Electrical Engineering

July
1936

Published Monthly by the
American Institute of Electrical Engineers

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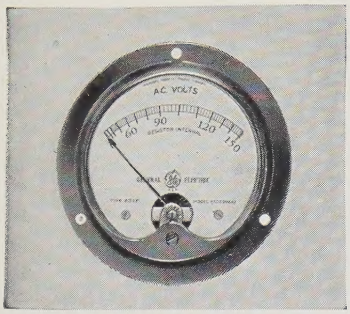

Small Panel Instruments
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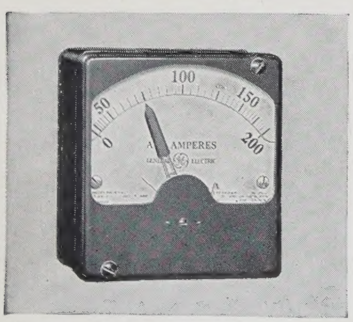

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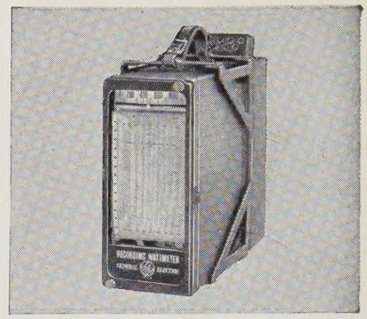

Recording Instruments
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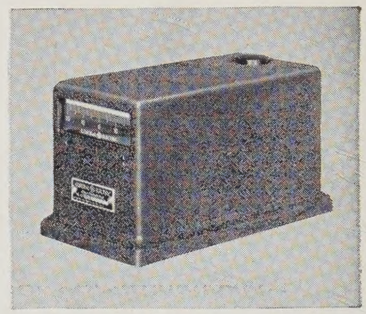

Galvanometers
(Bulletin GEA-2136)

Surge-crest Ammeter
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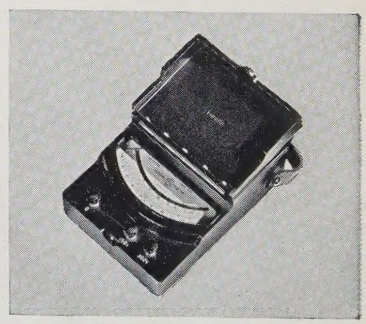

Medium-size Portables
(Bulletin GEA-1784)

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This Month—

Front Cover

Rays from a battery of 25 electric arc lights in the heart of the Texas Centennial Exposition Grounds at Dallas, as seen from White Rock Lake, 14 miles distant. Those attending the Institute's South West District meeting to be held in Dallas, October 26–28, 1936, will have an opportunity to visit the exposition, which will be open from June 6 to November 29.

Special Articles

A.I.E.E. Papers

—Turn to next page

In This Issue—

MANY members of the Institute's Schenectady, N. Y., Section and surrounding territory participated in a celebration held June 12–13, 1936 at Schenectady to commemorate the 50th anniversary of the establishment of the Edison Machine Works in that city, which later developed into the present General Electric Company. One of the events consisted of changing the name of Schenectady's River Road to Rice Road in honor of the late Past-President E. W. Rice, Jr. (*page 842*).

FREQUENCY tripling transformers have been suggested for furnishing 180 cycle electric energy to induction furnaces and to high-speed motor-driven apparatus from a 60 cycle source of supply. The use of series capacitance in the output circuits of these devices increases their maximum output and at the same time improves the output voltage regulation and input power factor (*pages 784–90*).

DIAL SWITCHING of short-distance toll telephone calls, introduced in Connecticut in 1929, has been extended until now about 70 per cent of such traffic in that area is handled by this method. The use of this system is said to afford definite improvements over earlier methods in speed and accuracy, in simple and more uniform operating practices, and in reducing operating effort (*pages 773–83*).

REGISTRATION of engineers, requirements for which are being strengthened in many states, is a subject that has been discussed in several previous issues. In the "Letters to the Editor" columns of this issue, Dr. D. B. Steinman, one of the leading exponents of registration, replies to comments on his previously published address "Registration of Engineers" (*pages 844–5*).

NOWHERE has the discovery of new phenomena brought about more complete modifications of older ideas than in the changes that concepts of atomic structure have undergone during the past 4 decades. A review of recent developments of investigations on nuclear structure, prepared by well-known authority, is included in this issue (*pages 760–7*).

JUNIOR engineers of Providence, R. I., have organized for professional development, in response to a suggestion made by the chairman of the committee on professional training of the Engineers' Council for Professional Development. Several groups have been set up in the new organization, each with a junior engineer as leader (*page 839*).

LIVING TISSUE of different animals has been found to have different electrical characteristics when considered as a conductor. Studies of living frog and human tissues emphasizes the fact that data obtained from electrophysiological studies of frogs cannot be applied directly to human beings (*pages 768–72*).

A COLD-CATHODE grid-controlled arc-discharge tube has been developed in which a discharge of several hundred amperes is controlled by an extremely small current. Although the tube was developed primarily for a stroboscopic light source, it has been used successfully for other purposes (*pages 790–4; 809*).

REVISED sphere-gap spark-over voltages have been compiled by a subcommittee of the A.I.E.E. committee on instruments and measurements. These revisions are to be included in a revised A.I.E.E. Standard, the text portion of which is now being prepared (*page 783*).

NATIONAL prize awards for 1935 A.I.E.E. papers, together with some District awards, were announced in the June issue; additional District awards are announced in this issue (*page 839*). Brief biographical sketches of some of the winners also are included in this issue (*pages 846–7*).

PLANS for the A.I.E.E. South West District meeting to be held at Dallas, Texas, October 26–28, 1936, already are under way. Those attending this meeting will have an opportunity to visit the Texas Centennial Exposition which opened in Dallas, June 6, 1936 (*page 838*).

REPORT of the A.I.E.E. board of directors to the membership for the fiscal year ending April 30, 1936, is published in this issue. The report includes the usual reports of standing committees and financial tabulations (*pages 795–808*).

DISCUSSIONS of papers presented at the 1936 A.I.E.E. winter convention, withheld from the preceding 2 issues to make room for the advance publication of summer convention papers, are resumed in this issue (*pages 809–37*).

AT THE annual business meeting of the Institute, held June 22, the first day of the 1936 summer convention, 9 members of the Institute were declared elected to serve as national officers of the Institute beginning August 1, 1936 (*pages 838; 841*).

ENGINEERS' relations to the present employment situation were discussed in a recent "News Letter" of American Engineering Council to its constituent bodies (*page 843*).

MEMBERSHIP of the Institute on April 30, 1936, the end of the fiscal year, showed a net increase for the year for the first time since 1931 (*pages 798–9*).

Interest and Appreciation

—A Message From the President

ONE cannot occupy the presidency of this great organization without being impressed with the tremendous volume of important activities being carried on continuously.

Having had the opportunity of visiting a large number of our sections from coast to coast during the past year I found on every hand evidence of a sincere loyalty and enthusiasm for the Institute and its ideals.

It is truly inspiring to learn the reactions of many of our members, particularly the younger engineers, toward the Institute's work. I have had the opportunity of talking to a large number and, almost without exception, they have shown a genuine interest not only in the activities and responsibilities of the various Section, Branch, and committee heads, but also in the broad policies and aims of the Institute as a whole. It is a most healthful indication.

The organization is not confining itself to its own peculiar problems alone. Since it is directly affected by national and local conditions, policies, and trends, these matters are being given thoughtful consideration, and each Section is assuming its rightful share of the responsibility for decisions.

I was indeed gratified to find that our members everywhere are taking an increasingly important part in the solution of local problems.

I have often said that over and above all things that may be regarded as specific contributions by the individual members of the Institute toward the furtherance of its aims, do we find the question of attitude as the one major responsibility. I repeat it here because it is even more indelibly impressed on my mind after this past year as your president.

It is significant that the new blood, the Enrolled Students and younger Associates, are taking a broad perspective of Institute affairs. They appear to be well informed on Institute matters and display evidence of having crystallized their thoughts and opinions in the direction of the greatest benefit to the largest number. They are giving wholehearted support to all our activities and fully realize that in so doing they are laying the groundwork not only for their own future professional and material welfare, but for that of the Institute as well.

It is thus that the proper attitude toward the American Institute of Electrical Engineers has pervaded the ranks of our future leaders. Nothing now in sight can prevent progressive intensification of the forward movement.

I feel that I would be failing in a major responsibility if I did not take this opportunity to express my appreciation to those who have done so much to aid me in carrying out the many duties entrusted to the office of president.

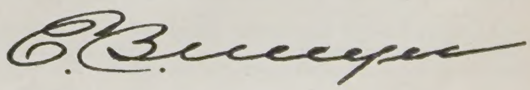
The members of the various committees and their respective chairmen deserve a large measure of praise for their eager co-operation in the conduct of Institute activities and affairs.

I have nothing but praise for the members of the headquarters staff. To their untiring efforts and devotion to all of the many phases of the Institute's work, we owe much of the success attained.

To my fellow officers and the board of directors I express my sincere gratitude. They have given unlimitedly of their energy and advice. I have thoroughly enjoyed working with them.

I commend the Section and Branch officers for the excellent work they have done.

It has been an honor and a privilege to serve as your president this past year and the many pleasant experiences and associations will live long in my memory. In relinquishing this office to my worthy successor I assure you that I will always feel a keen sense of pride in supporting the incoming officers and lending all the aid and assistance I can in making their administration as enjoyable as mine has been.



Exploring the Atomic Nucleus

A review of recent developments of investigations on nuclear structure, prepared at the request of the A.I.E.E. committee on education, is presented here.

By
SAUL DUSHMAN
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Schenectady, N. Y.

DISCOVERY of new phenomena always has brought about modifications of older concepts, or even the introduction of completely new ideas regarding the interpretation of the universe. This statement may be illustrated by numerous cases in the history of the development of physical science, but nowhere better than in the changes which our views on atomic structure have undergone during the past 4 decades.

In the middle of the nineteenth century the atom was regarded as the ultimate indivisible unit in the structure of matter. Toward the end of the century came the discovery of the electron by J. J. Thomson, the observations on radioactive phenomena by Becquerel, Mme. Curie, and Rutherford and Soddy, and the quantum theory of Planck. In 1911–1912 Rutherford set forth his nuclear theory which forms the basis of our present views on the nature of atomic structure, and in 1913 there were published Bohr's epoch making ideas on the origin of spectral lines that represented a fusion of Rutherford's nuclear model with Planck's atomistic views on the nature of radiant energy.

The Nuclear Atom

Consider briefly the essential features of the Rutherford-Bohr atom model. Within a sphere of radius ranging from 0.5 to 3×10^{-8} cm. there are N electrons moving about in a field of force due to the positive charge $+Ne$ (where e is the charge on an electron) on a nucleus of infinitesimally small dimensions located at the center of the atom. From observations on the collisions between alpha particles (nuclei of helium atoms) and atoms of various elements, it is known that the actual diameter of the nucleus is about 10^{-5} of that of the atom, and since the mass of the electron is only $^1/_{1836}$ of that of the H atom, although the highest value of N for any element is 92, approximately the whole mass of the atom must be concentrated in the nucleus.

Written especially for ELECTRICAL ENGINEERING, based upon an address given before a joint meeting of the A.I.E.E. Springfield Section and the Engineering Society of Western Massachusetts, at Springfield, Mass., Feb. 18, 1936.

The value of N varies from 1 for H, 2 for He, 3 for Li, and so on up to 92 for U, and corresponds to the order of the element in the Periodic Arrangement. It is possible to have 2 or more atomic species that are identical in value of N, but differ in the values of the atomic mass A. Such atoms, which correspond to the same chemical element (that is, have the identical place in the Periodic Arrangement), are known as *isotopes*. Nearly all the elements have been found to possess 2 or more isotopes. For instance, tin has 11 isotopes, hydrogen 3, oxygen 3, and mercury 5. The notation adopted for these isotopes consists in writing the chemical symbol with an index in the *upper* right hand corner to indicate the *mass* and a second index in the *lower* left hand (or right hand) corner to indicate the value of N. Thus the 3 isotopes of hydrogen and oxygen are designated by ${}_1H^1$, ${}_1H^2$, ${}_1H^3$, and ${}_8O^{16}$, ${}_8O^{17}$, ${}_8O^{18}$, respectively, where the values of N are 1 and 8 for H and O, respectively.

Radioactive Phenomena

In 1896 Becquerel observed that uranium salts emit a peculiar type of radiation which, like x-rays, can affect a photograph plate enclosed in a light tight box. Two years later Mme. Curie isolated radium, and other investigators discovered more elements that exhibited similar phenomena. In 1903 Rutherford and Soddy set forth their theory of spontaneous disintegration of radio-elements and showed that this process is accompanied by the expulsion of 2 types of particle, designated as alpha (α) and beta (β) particles, respectively. Whereas these particles could be deflected by a magnetic field, in opposite directions, a third type of radiation, designated as gamma (γ) rays was found to be unaffected by magnetic fields.

As an illustration of the successive transformations exhibited by the radioactive elements, Table I shows the successive disintegration products derived from radium.[1] The third column gives the value of the atomic number and the next column the "half-period,"[2] which, as may be observed, varies from 10^{-6} second to 1,590 years.

The final product of the series is Pb, and it may be observed that the series furnishes several cases of isotopic atoms.

We know now that the α particles are identical with the nuclei of helium atoms, that is, ${}_2He^4$, whereas the β particles are high speed electrons ($\bar{e}$) with velocities approaching that of light. These particles are emitted from the *nuclei*, as evidenced by their extremely high kinetic energies, so that spontaneous disintegration is a phenomenon characteristic of the nuclei of radioactive atoms.

Since the demonstration by v. Laue (1913) of the wave nature of X rays, it has been found that γ rays are of the same nature, but of much shorter wavelengths. The relation between the minimum wavelength of X radiation and the potential difference through which electrons have to be accelerated

1. Smithsonian Physical Tables, 8th Ed., Washington, 1933, p. 517.

2. By "half period" is meant the interval of time required for the spontaneous disintegration of one half of the initial amount of a given atomic species.

in an X ray tube in order to produce the radiation, is given by Einstein's equation

$$h\nu = hc/\lambda = Ve = (^1/_2)\mu v^2 \tag{1}$$

where

e = charge on electron = 4.770×10^{-10} electrostatic unit[3]
μ = mass of electron = 9.04×10^{-28} gram
h = Planck's constant = 6.547×10^{-27} erg. sec.
c = velocity of light = 2.998×10^{-10} cm. sec.$^{-1}$
v = velocity of electrons
ν = frequency of radiation
λ = wavelength of radiation

Expressing λ in centimeters, and V in *ordinary volts*, this relation becomes

$$\lambda = 12{,}336 \times 10^{-8}/V \text{ (cm. volt}^{-1}\text{)}.$$

Thus, X rays produced by electrons of 100,000 volts energy have a wavelength of 0.1234 $A°$ or 123.4 XU (1 A° = 10^3 XU = 10^{-8} cm.). However, the shortest γ rays known have a wavelength of about 5 XU, corresponding to electrons that have been accelerated through a potential difference of 2.62×10^6 volts. Because of the relation between λ and V, it is customary to designate γ rays of a definite wavelength by the corresponding value of V, and then to speak of radiation of V *electron volts* (*v.e.*).

Table I—Disintegration Products of Radium

Element	Symbol	N	T	Type of Emission	End Product
Radium	Ra	88	1590 years	α	Rn
Radon	Rn	86	3.83 days	α	RaA
Radium A	RaA	84	3.05 minutes	α	RaB
Radium B	RaB	82	26.8 minutes	β	RaC
Radium C	RaC	83	19.7 minutes	β	RaC′ (0.9996)
				α	RaC″ (0.0004)
Radium C′	RaC′	84	10^{-6} second	α	RaD
Radium C″	RaC″	81	1.32 minutes	β	RaD
Radium D	RaD	82	22 years	β	RaE
Radium E	RaE	83	4.9 days	β	RaF
Radium F	RaF	84	140 days	α	RaG
(Polonium)	(Po)				
Radium G	RaG	82			
(Lead)	(Pb)				

Equivalence of Energy and Mass

On the basis of Einstein's theory of relativity, energy and mass are mutually convertible, in accordance with the relation

$$E = c^2 \cdot m = 8.99 \times 10^{20} \cdot m \text{ (ergs)} \tag{2}$$

where m = mass in grams.

This relation has been found to account very satisfactorily for the changes in mass that occur in spontaneous disintegration of radioactive atoms and also, as will be shown, in the case of artificial transmutations. The mass that disappears is recovered in the form of kinetic energy of particles emitted or in that of gamma radiation. The relation also serves to indicate the magnitude of the energy involved in the formation of nuclei from their constituent units.

Incidentally, Einstein's relation is the explanation available at present for the emission of energy by the sun and stars. For every gram of mass lost, there is emitted a quantity of energy which amounts to 25×10^6 kilowatt-hours; that is, the total energy of combustion of about 2,500 tons of hard coal. The sun actually is radiating out into space about 4×10^6 tons per second, or 360,000 million tons per day. Yet in one million years, the sun has lost only about 7 per cent of its original mass.

In dealing with nuclear disintegration phenomena it is convenient to express changes of mass in terms of electron volts. The conversion factor is derived as follows.

For an element of unit atomic mass (the atomic mass of $_8O^{16}$ is taken as 16), the mass of an individual atom is $1/N_0 = 1/(6.064 \times 10^{23}) = 1.649 \times 10^{-24}$ g, where N_0 = Avogadro's constant = number of atoms per gram-atomic mass of any element. The energy equivalent ($c^2 \cdot m$) is 1.483×10^{-3} ergs per atom. Since the kinetic energy of an electron accelerated through 1 volt,

$$1 v.e. = 1.591 \times 10^{-12} \text{ ergs},$$

the disappearance of *1 unit of atomic mass* is equivalent to an energy evolution per atom of

$$\frac{1.483 \times 10^{-3}}{1.591 \times 10^{-12}} = 0.932 \times 10^9 \; v.e.$$

That is,

$$E = 0.932 \times 10^9 \Delta m \text{ (electron volts)} \tag{3}$$

where Δm is the *change in atomic mass*, or

$$10^6 \; v.e. = 0.001073 \text{ unit of mass.}$$

In ordinary chemical reactions, where the amount of energy evolved is of the order of only a few electron volts at most (1 *v.e.* corresponds to 23,054 calories per gram-atom) the change in mass equivalent to this energy is so infinitesimal as to be undetectable even by the most refined measurements. However, in the case of nuclear transmutations the energy changes involved are of the order of from 10^5 to 10^7 *v.e.* or even higher, and Einstein's relation has been found to be in satisfactory agreement with the results of observations.

Constituents of the Nucleus

In 1919 Rutherford observed that *protons*, p, that is *nuclei of hydrogen atoms* ($_1H^1$), are emitted when different atoms are bombarded by alpha particles.[4] This was the first case of artificial transmutation of elements, and in view of his observations the conclusion was drawn that the fundamental units or "building blocks" of the nuclei are *protons* and *electrons*, while a union of $4p + 2\bar{e}$, constituting an alpha particle, might be regarded as a stable, intermediate unit of nuclear structure.

3. Values of constants used in this article are taken from the publication by R. T. Birge, Phys. Rev. Supplement, v. 1 (1929), also in Smithsonian Physical Tables, 8th Ed., pages 103–7.

4. These observations are discussed by Sir Ernest Rutherford, J. Chadwick and C. D. Ellis, in Radiations From Radioactive Substances, The Macmillan Co., 1930; also by K. K. Darrow in *The Bell System Technical Jl.*, v. 10, p. 628–55 (1931).

However, radically new observations during the past 4 years have completely changed the views on the structure of atomic nuclei. Under different conditions it is found that the nuclei also are able to emit the following particles.[5]

1. *Neutrons*, which have approximately the same mass as protons but *no electric charge* (hence the symbol $_0n^1$ or n).

2. *Positrons*, which are *positively* charged particles of the same mass at the electron (designated by $\overset{+}{e}$).

In addition, some theoretical physicists have brought forward valid reasons for assuming that there also exist in the nucleus the following:

1. *Neutrinos*, that is, particles having a mass equal to or less than that of the electron or positron, but *zero* charge, and

2. *Negatrons*, that is, particles of the same mass as the proton, but *negatively* charged.

At the present time the experimental evidence for the existence of either a neutrino or negatron is extremely meager, but from a theoretical point of view there are fairly cogent arguments in favor of their acceptance.[6]

In view of the observations on the properties and mode of behavior of neutrons (which will be discussed more fully in a subsequent section), it is the accepted point of view at present that the *fundamental units of nuclear structure are neutrons and protons*, with the alpha particle (a union of $2n + 2p$) as an intermediate unit. Table II[7] shows the manner in which the nuclear structures are assumed to be built up, in the case of several of the elements of lower atomic number.

With regard to the nuclear masses, there has been considerable discussion. On the one hand, there is the actual mass spectrographic data obtained by F. W. Aston and K. Bainbridge,[8] and on the other hand there are available energy relations between the nuclei as observed in disintegration phenomena. During the past year both H. Bethe[9] and, independently, M. L. E. Oliphant, A. E. Kempton and Lord Rutherford[10] have considered all the probable causes of errors, and reached conclusions, which are in substantial agreement, regarding the values for the nuclei of elements ranging from H to O. The values given in Table II by Pool are based upon those published by these investigators, and therefore undoubtedly represent the best opinion available.

All the isotopes as far as those for Na are given. For the elements of higher atomic number, only a few selected ones are given in the table, mostly to illustrate the application that has been made of the hypothetical *negatron* (indicated by $\bar{p}$).

On the basis of Einstein's equivalence relation, the *mass defect of a nucleus actually is a measure of the energy of binding of the constituent neutrons and protons.* If the value 1.0083 for the mass of the neutron, as recently deduced by J. Chadwick and M. Goldhaber (see subsequent discussion), be accepted, there may be deduced for example, the following conclusions.

5. See the excellent review by K. K. Darrow, THE NUCLEUS, *The Bell System Technical Jl.*, v. 12, p. 288–330 (1933); v. 13, p. 105–58 (1934).

6. See discussion of the neutrino in papers by G. Beck, International Conference on Physics, p. 31; and by C. D. Ellis, ib. p. 43. Arguments for the negatron are given by G. Gamow, ib. p. 60; also W. J. Henderson, *Proc. Camb. Phil. Soc.* v. 31, p. 285 (1935).

7. M. L. Pool, ENERGIES AND PRODUCTS INVOLVED IN NUCLEAR DISINTEGRATION AND SYNTHESIS, Sigma Xi Symposium on the Nucleus of the Atom and its Structure, *The Ohio Journal of Science*, v. 35, p. 343–61 (1935).

8. F. W. Aston, MASS-SPECTRA AND ISOTOPES, 1933, *Nature*, v. 135, p. 541 (1935); K. Bainbridge, *Jl. Franklin Inst.*, v. 215, p. 509 (1933); *Phys. Rev.*, v. 43, p. 103, 424 (1933).

9. *Phys. Rev.*, v. 47, p. 633 (1935).

10. *Proc. Roy. Soc., A*, v. 150, p. 241 (1935).

Table II—Structures and Masses of Stable Nuclei

Nucleus	Structure	Mass	Nucleus	Structure	Mass
$_1H^1$	p	1.00807	$_9F^{19}$	$4\alpha nnp$	19.0031
$_1H^2$	np	2.01423	$_{10}Ne^{20}$	5α	19.99671
$_1H^3$	npn	3.01610	$_{10}Ne^{21}$	$5\alpha n$	....
$_2He^3$	pnp	3.0172	$_{10}Ne^{22}$	$5\alpha nn$	21.99473
$_2He^4$	α	4.00336	$_{11}Na^{23}$	$5\alpha nnp$	
$_2He^5$	αn	5.010	$_{12}Mg^{24}$	6α	
$_3Li^6$	αnp	6.01614	$_{13}Al^{27}$	$6\alpha nnp$	
$_3Li^7$	αnpn	7.01694	$_{14}Si^{28}$	7α	27.9818
$_4Be^8$	2α	8.007	$_{15}P^{31}$	$7\alpha nnp$	30.9825
$_4Be^9$	$2\alpha n$	9.0135	$_{16}S^{32}$	8α	
$_5B^{10}$	$2\alpha np$	10.0146	$_{17}Cl^{35}$	$8\alpha nnp$	34.893
$_5B^{11}$	$2\alpha npn$	11.0111	$_{18}A^{36}$	9α	35.976
$_6C^{12}$	3α	12.0037	$_{17}Cl^{37}$	$9\alpha\bar{p}$	36.980
$_6C^{13}$	$3\alpha n$	13.0069	$_{18}A^{38}$	$9\alpha\bar{p}p$	
$_7N^{14}$	$3\alpha np$	14.0076	$_{18}A^{40}$	$9\alpha\bar{p}pnn$	39.971
$_7N^{15}$	$3\alpha npn$	15.0053	$_{20}Ca^{40}$	10α	
$_8O^{16}$	4α	16.0000	$_{19}K^{41}$	$10\alpha\bar{p}$	
$_8O^{17}$	$4\alpha n$	17.0040	$_{20}Ca^{42}$	$10\alpha\bar{p}p$	
$_8O^{18}$	$4\alpha nn$	18.0065			

1 The dissociation of the nucleus of "heavy" hydrogen, the deuteron ($_1H^2$), would require an energy absorption corresponding to an increase in mass of $1.0081 + 1.0083 - 2.0142 = 0.0022$ unit, that is 2.05×10^6 *v.e.*

2. The energy of binding of $2n + 2p$ to form an α particle is 27.4×10^6 *v.e.*, corresponding to the decrease in mass of $2\,(1.0081 + 1.0083) - 4.0034 = 0.0294$ unit.

By similar arguments it is readily deduced that the energy of binding of neutrons and protons in the formation of nuclei ranges from 2 or 3 million volts to values which are 10 times as great, and even higher.

There seems to be some question regarding the stability of *He*^{3}, since the structure assigned to it in Table II is out of line with those assigned to other nuclei. However, this is only one of the infinitely large number of yet unsolved problems in nuclear physics.

RUTHERFORD'S EXPERIMENTS ON ARTIFICIAL TRANSMUTATION

As mentioned already, Rutherford succeeded in 1919 in producing the first case of artificial transmutation by bombarding nitrogen with α particles. Protons were found to be emitted with high speed.[11] Similar observations were made with other nuclei. Table III shows some of the reactions observed and their interpretation on the basis of nuclear structures.

The reaction consists in the capture of the α particle followed by the ejection of a proton. Figure 1 shows a photograph, taken by means of a C. T. R. Wilson expansion chamber, of such a transmutation.[12] Inserting values for the nuclear masses, it is seen that in the bombardment of nitrogen there is a net increase of 0.001 unit of mass, corresponding to an

11. For an account of these investigations see K. K. Darrow, *The Bell System Technical Jl.*, v. 10, p. 628–55 (1931).

12. K. K. Darrow, loc. cit.

energy absorption of about 10^6 *v.e.* However, in the third reaction there is a net evolution of about 3×10^6 *v.e.* Rutherford found that these transmutations could be carried out only with α particles having a kinetic energy in excess of 10^6 *v.e.* and that the efficiency is extremely low. Even for α particles of energy of 8×10^6 *v.e.*, "about 1 particle in 10^5 or 10^6 is able to effect a transformation in the nucleus of a light element."[13]

Quantum Theory of Nuclear Disintegration

On the basis of Newtonian mechanics, no explanation of the observations on spontaneous disintegration of nuclei could be suggested. However, the advent of the new quantum mechanics (1925–6) led to a very satisfactory interpretation, which was developed independently by R. W. Gurney and E. U. Condon[14] on the one hand, and G. Gamow[15] on the other.

From the experiments on the scattering of α particles by atomic nuclei, it is concluded that the Coulomb field of repulsion must be valid for distances as low as 10^{-12} centimeters from the center of the nucleus. This means that for distances greater than that, the potential energy function U for an α particle ($N = 2$) approaching the nucleus is represented by a hyperbola ($U = 2Ne^2/x$, where x is the distance from center of nucleus). Since, however, the α particle actually is a constituent of the nucleus, the potential energy function must decrease to zero and lower, corresponding to attraction, for $x < 10^{-12}$ centimeters. In figure 2 the function U is indicated by the full curve, for the hyperbolic portion, and by the dotted line for the part nearer the nucleus.

Table III—Transmutations by Alpha-Particle Bombardment

$_7N^{14} + {_2He^4}$	$\longrightarrow$	$_8O^{17} + {_1H^1}$
$3\alpha n p + \alpha$	$\longrightarrow$	$4\alpha n p + p$
$14.0076 + 4.0034$	$=$	$17.0040 + 1.0081 - 0.0010$
$_{13}Al^{27} + {_2He^4}$	$\longrightarrow$	$_{14}Si^{30} + {_1H^1}$
$6\alpha n n p + \alpha$	$\longrightarrow$	$7\alpha n n + p$
$_5B^{10} + {_2He^4}$	$\longrightarrow$	$_6C^{13} + {_1H^1}$
$2\alpha n p + \alpha$	$\longrightarrow$	$3\alpha n + p$
$10.0146 + 4.0034$	$=$	$13.0069 + 1.0081 + \mathit{0.003}$

Now, classically, an α particle in the region I (figure 2) having a kinetic energy indicated by the height of the horizontal line E in the figure, never can escape from the nucleus. But, on the basis of quantum mechanics, there exists a *definite probability for the penetration of the α particle through the barrier.* The theory shows that the probability for the occurrence of this "tunnelling effect" should increase exponentially with decrease in both the value of $U_m - E$ and the width of the barrier at the height E (where U_m is the maximum value of U).

To test this theory, Gurney and Condon calculated the relative periods of Ur, RaA and RaC′ from the observed values for the kinetic energies of the emitted α particles. The horizontal lines in figure 2 have been drawn at the corresponding values of E, and on the basis of the theory the values of T (the half-period as given in Table I) should decrease in passing from Ur through RaA to RaC′ according to definite ratios. The agreement between the ratios thus calculated and those observed was found to be very satisfactory.

The theory subsequently was extended by Gamow to the prediction that there also exists a small probability for the *penetration into the nucleus* by a particle of relatively low energy, such as might be obtained by accelerating a proton or deuteron through a potential difference of only 100,000 volts.

Transmutations Produced by Protons and Deuterons

While Gamow's conclusions have not been confirmed quantitatively, the qualitative results have been in signal agreement. Since the first experiments of this nature by J. D. Cockcroft and E. T. S. Walton in Cambridge, England, many other investigators both in America and abroad have been interested in developing equipment by means of which streams of protons or deuterons can be obtained both at high velocities and in copious numbers. While Cockcroft and Walton, H. R. Crane and C. C. Lauritsen of the California Institute of Technology, and others have used high voltage direct current generating apparatus, E. O. Lawrence of the University of California (Berkeley) has developed the so-called cyclotron, in which the ions are given successive increments in kinetic energy by a special arrangement of a powerful magnetic field and high frequency circuit of relatively low voltage. Furthermore, R. V. Van de Graaff, of Massachusetts Institute of Technology, has been working on a high voltage static machine by which it is expected to generate potentials as high as 10×10^6 volts, and other machines of a similar nature are under construction in other laboratories.

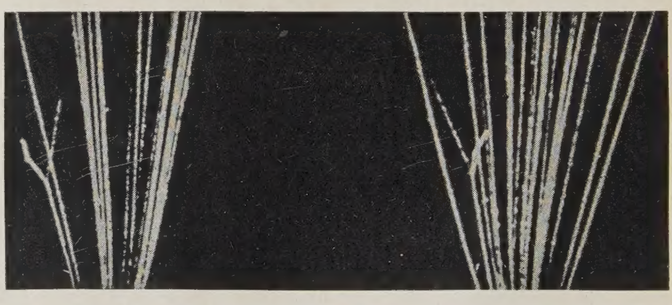

Fig. 1. Transmutation of a nitrogen atom attended by capture of the impinging alpha-particle (P. S. Blackett)

In their earliest experiments, carried out in 1932, Cockcroft and Walton used a stream of protons accelerated through a potential difference of only about 300,000 volts. When these were projected at nuclei

13. Lord Rutherford, International Conference on Physics, London 1934, p. 11; Physical Soc. London, 1935.
14. *Phys. Rev.*, v. 33, p. 127 (1929).
15. *Zeits. f. Physik.*, v. 51, p. 204 (1928).

of lithium atoms, the emission of high speed α particles was observed in accordance with the first equation in Table IV. The 2 α particles are emitted simultaneously, and have a kinetic energy of 8.5×10^6 *v.e.* per particle. This would correspond to a calculated *decrease* in mass, in the reaction, of 0.0182 unit (see last column of Table IV), whereas the

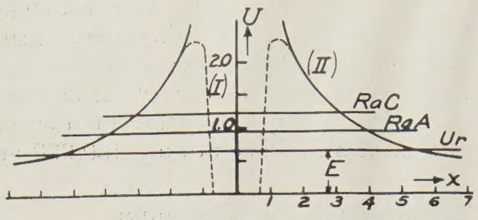

Fig. 2. Potential energy curve for alpha particle in nucleus of radioactive atom

decrease in mass calculated from the nuclear masses (as given in Table II) is 0.0183. Thus, the agreement is excellent.

Figure 3 shows the observations made by 3 different sets of investigators[16] on the rate of production of α particles as a function of the energy of incident protons. Even at as low as 30,000 volts there are some disintegrations, but the efficiency of disintegration increases rapidly with increase in voltage. The absolute yields, or the number of disintegrations *per* 10^9 *protons* are stated by Henderson to be as follows: 2.0 at 250,000 volts, 10.2 at 500,000 volts and 40 at 1,000,000 volts.

Table IV contains a list of similar disintegrations produced by bombarding nuclei of atoms other than those of Li. According to Livingston and Lawrence[17] there is evidence that "the energy of bombarding protons requisite for nuclear penetration is approximately proportional to the atomic number."

It also is worth noting that H. R. Crane, C. C. Lauritsen, and A. Soltan[18] have succeeded in using high speed helium ions to produce transmutations in which neutrons were emitted.

As mentioned already, deuterons ($_1H^2$) also have been used by investigators, especially since supplies of "heavy" water have become available. In these cases, neutrons are obtained along with α particles. A few such reactions are shown in Table IV. The data in the last 2 columns of this table are taken from the paper by Oliphant, Kempton, and Lord Rutherford,[19] and show the very good agreement obtained between observed values of energy evolved and the decrease in mass calculated on the basis of the values given in Table II.

The Neutron[20]

Earlier observations made by German investigators on an extremely penetrating "radiation" obtained from the bombardment of Be atoms by α particles from Po were repeated early in 1932 by Irene Curie, the daughter of Mme. Curie, and her husband F. Joliot. They concluded that the radiation consists of extremely short wave gamma rays. Thereupon J. Chadwick also took up the problem, and on Feb. 27, 1932, he reported his conclusion that these radiations consist of a new type of particle which he designated as the *neutron.*

According to Chadwick's view, the reaction involved in the bombardment of Be nuclei by α particles is of the form shown in equation 1 of Table V.

The neutrons themselves, because they have no electric charge, produce no ionization and no visible tracks in the C. T. R. Wilson expansion chamber. Therefore, the only method by which they may be detected is by the high speed nuclei which they eject by collision. That such collisions are relatively infrequent is evident from the fact that a proton of velocity 3×10^9 centimeters-sec.$^{-1}$ travels about one foot in air, while a neutron of the same velocity will travel, on the average, about 1,800 feet before losing its energy by collosion with a nitrogen nucleus. Even in passing through such a dense material as lead, only about 13 per cent of the incident neutrons are absorbed by one centimeter thickness. These and similar observations have led J. R. Dunning and G. B. Pegram to the conclusion[21] that the collision radius of the neutron is about 1.3×10^{-13} centimeters.

Neutrons also have been obtained by bombardment of other nuclei with α particles, as shown in Table V. In each case the resulting nucleus has a charge 2 units higher and an atomic mass 3 units higher than that of the bombarded nucleus. The emission of neutrons often is accompanied by the emission of protons, as shown in Table III. Furthermore, as indicated previously, neutrons also have been obtained as a result of bombarding nuclei with high speed deuterons (see Table IV) and with helium ions.

It should be mentioned that the nuclei N^{13}, and Na^{22}, referred to respectively in equation 10 of Table III and equation 3 of Table V, are unstable nuclei. As will be pointed out in a subsequent section these are intermediate states in the artificial production of radioactivity.

Table IV—Transmutations by High Speed Protons and Deuterons

	Reaction	Nuclear Change	Δm (Table II)	$\Delta m = E/c^2$
(1)	$Li^7 + H^1 \longrightarrow 2He^4$	$\alpha n p n + p \longrightarrow 2\alpha$	0.0183	0.0182
(2)	$Be^9 + H^1 \longrightarrow Li^6 + He^4$	$2\alpha n + p \longrightarrow \alpha n p + \alpha$	0.0022	0.0022
(3)	$B^{11} + H^1 \longrightarrow 3He^4$	$2\alpha n p n + p \longrightarrow 3\alpha$	0.0088	0.0090
(4)	$F^{19} + H^1 \longrightarrow O^{16} + He^4$	$4\alpha n n p + p \longrightarrow (4\alpha) + \alpha$	0.0078	
(5)	$Li^6 + H^2 \longrightarrow 2He^4$	$\alpha n p + n p \longrightarrow 2\alpha$	0.0236	0.0237
(6)	$Li^6 + H^2 \longrightarrow Li^7 + H^1$	$\alpha n p + n p \longrightarrow \alpha n p n + p$	0.0055	0.0053
(7)	$Be^9 + H^2 \longrightarrow Li^7 + He^4$	$2\alpha n + n p \longrightarrow \alpha n p n + \alpha$	0.0077	0.0077
(8)	$Be^9 + H^2 \longrightarrow B^{10} + n^1$	$2\alpha n + n p \longrightarrow 2\alpha n p + n$	0.0054	0.0053
(9)	$Li^7 + H^2 \longrightarrow 2He^4 + n^1$	$\alpha n p n + n p \longrightarrow 2\alpha + n$	0.0161	0.0156
(10)	$C^{12} + H^2 \longrightarrow N^{13} + n^1$	$3\alpha + n p \longrightarrow 3\alpha p + n$	......	......
(11)	$B^{11} + H^2 \longrightarrow C^{12} + n^1$	$2\alpha n p n + n p \longrightarrow (3\alpha) + n$	0.0133	......

16. J. D. Cockcroft and E. T. S. Walton, *Proc. Roy. Soc. A*, v. 137, p. 229 (1932); v. 136, p 619 (1932); v. 129, p. 477 (1930).
E. O. Lawrence, M. S. Livingston and White, *Phys. Rev.*, v. 42, p. 150 (1932); M. C. Henderson, *Phys. Rev.*, v. 43, p. 98 (1933).
17. *Phys. Rev.*, v. 43, p. 369 (1933).
18. *Phys. Rev.*, v. 44, p. 514 (1933); v. 45, p. 507 (1934).
19. Loc. cit.
20. J. Chadwick, The Neutron, *Proc. Roy. Soc. A*, v. 142, p. 1–25 (1933).
21. *Phys. Rev.*, v. 43, 497 (1933).

From his investigations in 1932, Chadwick deduced for the mass of the neutron the value 1.0067, which is less than the mass of the proton (1.0081). E. O. Lawrence derived a still smaller value (1.0006), while Curie and Joliot favored a much larger value (1.012). During the past few months J. Chadwick and M. Goldhaber[22] have made a fresh determination by using the observations on the disintegration of deuterons by gamma rays.

In presence of gamma rays from ThC″ ($\lambda = 4.710 \times 10^{-11}$ centimeters and corresponding energy, $h\nu = 2.62 \times 10^6$ *v.e.*), deuterons are decomposed into neutrons and protons. If W denote the energy required to dissociate the deuteron in accordance with the reaction

$$H^2 \longrightarrow H^1 + n^1 - W/c^2$$

then the excess energy, $h\nu$-W, must appear in the form of kinetic energy of neutrons and protons. Since actual observation shows that $h\nu - W = 0.52 \times 10^6$ *v.e.*, it follows that $W = 2.1 \times 10^6$ *v.e.*, and $W/c^2 = 0.00225$ unit of mass. Hence,

$$n^1 = 2.0142 - 1.0081 + 0.00225$$
$$= 1.00835.$$

This conclusion is in agreement with the generally accepted view that the *neutron is an elementary stable particle*, and that nuclei are built up of neutrons and protons as fundamental units. On this basis, it should require absorption of energy to decompose either of the particles with formation of the other. This conclusion is readily made evident by considering the possible reactions.

(1) $H^1 \longrightarrow n^1 + \overset{+}{e} - \Delta m_1,$

(2) $n^1 \longrightarrow H^1 + \overset{-}{e} - \Delta m_2.$

In these equations, Δm_1 and Δm_2 each must be greater than zero in order that H^1 and n^1 shall be stable. Assuming that the mass of $\overset{+}{e}$ is the same as that of $\bar{e}$, that is 0.00055, and accepting the value 1.0083 for n^1, it follows that*

$\Delta m_1 = 0.00078$, corresponding to 7.27×10^5 *ve* and
$\Delta m_2 = 0.00032$, that is, 2.98×10^5 *ve*

Table V—Production of Neutrons by Alpha Particles

(1)	$Be^9 + He^4 \longrightarrow C^{12} + n^1$
	$2\alpha n + \alpha \longrightarrow (3\alpha) + n$
(2)	$B^{11} + He^4 \longrightarrow N^{14} + n^1$
	$2\alpha np n + \alpha \longrightarrow 3\alpha np + n$
(3)	$F^{19} + He^4 \longrightarrow Na^{22} + n^1$
	$4\alpha nnp + \alpha \longrightarrow 5\alpha np + n$

The neutron has proved a useful tool in transmutation of nuclei. N. Feather[23] observed the transmutation indicated by the reaction,

$${}_7N^{14} + {}_0n^1 \longrightarrow {}_5B^{11} + {}_2He^4,$$

which is the reverse of the mode of formation of neutrons by bombardment of nuclei with high speed α particles. By collision with the nuclei ${}_8O^{16}$, ${}_6C^{12}$ and ${}_{10}Ne^{20}$, the latter are transmuted into ${}_6C^{13}$, ${}_4Be^9$ and ${}_8O^{17}$ respectively, with ejection of α particles.

Because it is infinitesimally small and has no charge, the neutron can penetrate the potential barriers of the heavier nuclei and thus produce transmutations which are not possible with charged particles such as H^1, H^2 or He^4. E. Fermi[24] has found that out of 60 elements which he has investigated, it was possible by this method to obtain transmutation in 40 cases.

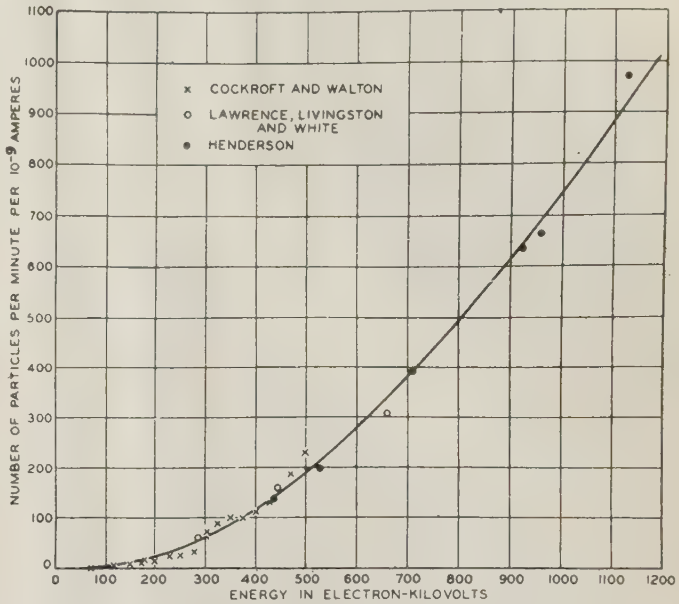

Fig. 3. Variation with proton energy of rate of disintegration of lithium atoms

There is considerable evidence that in these experiments, and similar ones carried out by other investigators, the neutron is captured by the nucleus with the resulting formation of an unstable atom, or capture is followed by α particle (or proton) emission.

The Positron

The discovery of the positron in 1932 by C. D. Anderson[25] of the California Institute of Technology, was the by-product of an investigation on the nature of cosmic rays. An expansion chamber was set up surrounded by a magnetic field parallel to the axis of the chamber. Thus any charged particles produced by the rays would be deflected in the field and oppositely charged particles would be deflected in opposite directions. If e/μ denotes the ratio of charge to mass, v the velocity of the particle, and H the magnetic field strength, the radius of curvature of the path, ρ, is given by the relation

$$\rho = \frac{v}{H} \cdot \frac{\mu}{e}$$

22. *Proc. of Roy. Soc. A*, v. 151, 479 (1935).
23. *Proc. Roy. Soc. A*, v. 136, p. 709 (1932).
* See note at end of article.

24. International Conference on Physics, p. 75, 1934.
25. *Phys. Rev.*, v. 43, p. 491–94 (1933).

Moreover, Anderson inserted in the expansion chamber a plate of lead, 6 millimeters thick, to act as a barrier by which any particles liberated by the cosmic rays would be stopped or slowed down. "In August 1932," he states, "a photograph was obtained which showed clearly a particle of positive charge passing through the plate of lead and emerging with a lower energy. The evidence presented by this photograph was so clear-cut that after the negative film was removed from the developing bath and before it was dry, we reached the conclusion that this particle might represent a positive electron."[26]

Figure 4 is a reproduction of this photograph which is the birth certificate, as it were, of the *positron*. In March 1933, P. M. S. Blackett and G. P. S. Occhialini in Cambridge, England, confirmed Anderson's observations, and then together with J. Chadwick showed that positrons are produced not only by cosmic rays but in the course of artificial transmutation by use of α particles. Anderson observed that positive and negative electrons are formed from cosmic rays in pairs, the range of electron velocities being from 60 to 5,000 $\times$ 10^6 *v.e.* and that of positrons from 120 to 2,700 $\times$ 10^6 *v.e.*

The most interesting mode of formation of positrons is that observed by Anderson and Neddermeyer[27] in which the characteristic gamma rays of ThC$''$ (energy = 2.6 $\times$ 10^6 *v.e.*) *produce positive and negative electrons in pairs*. Figure 5 shows the tracks of such an electron pair in argon. In this case there is *a conversion of* radiation into material particles. That is, $h\nu = 2c^2 \cdot \mu$, where $h\nu$ is the energy of the photons of gamma radiation and μ is the mass of either electron or positron.

On this basis the energy required should be approximately 10^6 *v.e.*, and actual observation shows that photons with an energy less than this do not undergo the transformation.

Furthermore, the laws of conservation of energy and momentum require the presence of a nucleus at which such a transformation of radiation into matter can occur, so that this process is impossible in empty space.

The discovery of the positron also confirmed a mathematical prediction made by Dirac in the form of an equation, known as the Dirac Electron Equation. As Anderson points out,[28] "This equation proved remarkably successful in solving a variety of problems that hitherto had baffled the theorists; but it contained one very striking feature that was a source of considerable annoyance. It required that under certain conditions electrons should have a negative energy and negative mass; they should have less than zero energy and weigh less than nothing. Dirac considered each point in space, including empty space or a perfect vacuum, to be 'filled' with an infinity of such negative energy electrons. He also made the assumption that these negative mass electrons were unobservable and it was a property of free space that they should be there. Dirac stated in 1930 that if one of these electrons should be removed, the 'hole' in space that remained would manifest itself as an electron of positive electrical charge and of positive mass and energy. The logic is perfect, for taking away less than nothing from space is equivalent to putting something there."

The theory of Dirac requires that the life of the positron should be very short, less than 10^{-6} sec.

Fig. 4. Track of a positive electron which has passed through a lead plate

When a positron meets an electron, both particles suffer complete annihilation, and their mass is replaced by the energy of 2 gamma ray photons—another instance of the validity of Einstein's mass-energy equivalence relation.

Induced Radioactivity[29]

Curie and Joliot observed in 1933 that when boron is bombarded by alpha particles, alternative reactions may occur: either a proton may be emitted, as observed by Rutherford, or a neutron and positron, as though a proton had been dissociated. In 1934 the same investigators found that *the emission of positrons persists even after the alpha particle bombardment ceases*. They attributed this phenomenon to the formation of an unstable intermediate product (N^{13}) according to the following scheme:

$${}_5B^{10} + {}_2He^4 \longrightarrow {}_7N^{13} + {}_0n^1$$

Then

$${}_7N^{13} \longrightarrow {}_6C^{13} + e$$

This, the first instance of *induced radioactivity*, has been followed up since then by a large number of similar observations in which not only alpha particles, but also neutrons, protons, and deuterons have been used as bombarding particles.

Thus, E. O. Lawrence, M. C. Henderson, and S. M. Livingston observed that radio-nitrogen (the designation for the ${}_7N^{13}$ atom) can be formed by the reactions:

$${}_1H^2 + {}_6C^{12} \longrightarrow {}_7N^{13} + {}_0n^1$$

and

$${}_1H^1 + {}_6C^{12} \longrightarrow {}_7N^{13}.$$

When deuterons are used, the reaction consists in the majority of cases in the capture of the neutron

26. *General Electric Review*, v. 37, p. 534–40 (1934).
27. *Phys. Rev.*, v. 43, p. 1034 (1933).
28. Loc. cit.
29. E. O. Lawrence, Sigma Xi Symposium, pp. 388–405 (1935).

and the emission of a high speed proton, as for instance in the formation of radio-sodium (an unstable atom which has a half-life of 15 hours) and in that of radio-phosphorus (for which the half-life is 14 days). The reactions in these 2 cases are as follows:

(1) ${}_{1}H^{2} + {}_{11}Na^{23} \longrightarrow {}_{11}Na^{24} + {}_{1}H^{1}$

${}_{11}Na^{24}$ (radio-active) $\longrightarrow {}_{12}Mg^{24} + \bar{e}$

(2) ${}_{1}H^{2} + {}_{15}P^{31} \longrightarrow {}_{15}P^{32} + {}_{1}H^{1}$

${}_{15}P^{32}$ (radio-active) $\longrightarrow {}_{16}S^{32} + \bar{e}$.

In the first case the emitted beta particle has an energy of 3 million volts, and in the second case, 1.7 million volts.

In the case of the heavier elements, E. Fermi and his associates[30] have succeeded in obtaining several radio-elements by neutron bombardment. As pointed out previously, the neutron can penetrate the nuclei of atoms of higher atomic number where charged particles are unable to do so because of the presence of a potential barrier.

The neutrons may be generated by collisions of photons with nuclei of beryllium or deuterium, as in the case of the gamma rays from ThC″. Thus A. Brasch, F. Lange and A. Waly[31] have shown that X rays of from 2 to 3 million volt energy in presence of beryllium are capable of producing radio active nuclei through the production of neutrons.

It therefore seems possible, in view of these observations and as a result of the intensive work in progress in this field at present, that in the near future there will be available several artificially produced radio-elements which will compete commercially with radium.

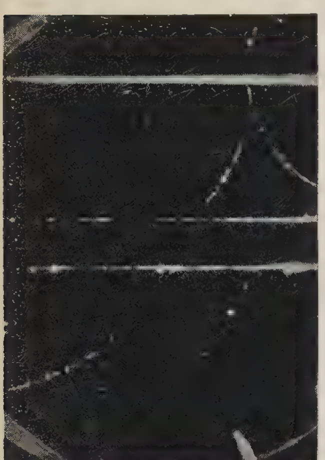

Fig. 5. Paths of a pair of electrons, one positive and one negative, ejected downward from a plate of lead by gamma rays

Table VI, compiled by M. L. Pool[32] from the paper by E. Fermi, gives a list of some of the radioactive atoms. The fourth and fifth columns give the energy and sign of the emitted particle, while the last column gives the method of production. Thus C^{11} is produced by the action of deuterons (d) on B^{10}, while N^{13} may be produced by one of 3 methods: protons or deuterons on C^{12}, and α particles on B^{10}.

In conclusion we cannot do better than quote the comments by E. O. Lawrence on the "Utility of Artificial Radioactivity:"[33]

"Now," he writes, "that radioactive forms of many of the elements can be manufactured in the laboratory, many new avenues of research are opened up. It is reasonable to expect that artificial radioactive substances will play a possibly more important rôle in the physical and biological sciences in the not distant future than the natural radioactive substances have in the past. Certainly extensive study of the artificial radioactive substances will lead to a greatly enlarged understanding of atomic structure. But, more particularly, these new radioactive substances provide many and varied ideal sources of beta and gamma rays. For example, radio-phosphorus provides beta radiation free from gamma rays, that can be used conveniently for studies of the behavior of high speed electrons in matter. Also some of the new radioactive substances give off gamma rays that are far more energetic and penetrating than any from the natural radioactive substances, and the use of these gamma ray sources undoubtedly will lead to important advances in our knowledge of the interaction of radiation and matter."

Table VI—Synthesized Radioactive Nuclei

Nucleus	Structure	Life	Energy of e	Sign of Charge	Method of Production
$2He^{3}$	pnp				pLi^{6}; $d(H^{2}, B^{9})$
${}_{2}He^{6}$	αnn				
${}_{3}Li^{5}$	αp				
${}_{3}Li^{8}$	$\alpha nnpn$	0.5 sec.	9.0 mV max.	−	dLi^{7}
${}_{4}Be^{7}$	αpnp				
${}_{4}Be^{10}$	$2\alpha nn$		0.3 mV av.	−	dBe^{9}; αLi^{7}
${}_{5}B^{9}$	$2\alpha p$	1.0 min.	0.5 mV av.	+	αLi^{6}
${}_{5}B^{12}$	$2\alpha nnpn$	0.02 sec.	11.0 mV max.	−	dB^{11}
${}_{6}C^{11}$	$2\alpha pnp$	20.0 min.	1.3 mV max.	+	dB^{10}
${}_{6}C^{14}$	$3\alpha nn$				
${}_{7}N^{13}$	$3\alpha p$	11.0 min.	1.5 mV max.	+	pC^{12}; dC^{12}; αB^{10}
${}_{7}N^{16}$	$3\alpha nnpn$	9 0 sec.		−	nF^{19}
${}_{8}O^{15}$	$3\alpha pnp$	126.0 sec.	1.2 mV max.	+	dN^{14}
${}_{8}O^{19}$	$4\alpha nnn$	40.0 sec.		−	nF^{19}
${}_{9}F^{17}$	$4\alpha p$	1.16 sec.		+	αN^{14}
${}_{9}F^{18}$	$4\alpha np$			+	
${}_{9}F^{20}$	$4\alpha nnpn$	12.0 sec.	4.5 mV max.	−	nNa^{23}; dF^{19}
${}_{10}Ne^{19}$	$4\alpha pnp$			+	
${}_{10}Ne^{23}$	$5\alpha nnn$	40.0 sec.		−	$n(Na^{23}, Mg^{26})$

NOTE: Subsequent to completion of the typography of this paper there was published a comprehensive discussion on nuclear physics by H. A. Bethe and R. F. Bacher in *Reviews of Modern Physics*, volume 8, April 1936, page 82. The paper deals especially with the structures of atomic nuclei and the wave mechanics interpretation of the interaction of neutrons and protons. While no special table of nuclear masses is given, the authors assign the mass 1.00845 to the neutron instead of 1.0083 as given in this article. Also the masses assigned to some of the other nuclei are slightly different. However, this does not affect the validity of the argument given in the present article for the conclusion that the neutron is an elementary stable particle. The change in the value of the mass of the neutron would alter the value of Δm_1 (deduced in the section on "The Neutron") from 0.00078 to 0.00093 and that of Δm_2 from 0.00032 to 0.00017.

30. *Proc. Roy. Soc. A*, v. 146, p. 483 (1934); also ib., v. 149, p. 522 (1935).
31. *Nature*, v. 134, p. 880 (1934).
32. Loc. cit.
33. Loc. cit.

Electrical Studies of Living Tissue

Electrical studies of living frog and human tissues emphasize the fact that data obtained from electrophysiological studies of frogs cannot be applied directly to human beings. These studies show that frog tissue is practically equivalent to a pure resistance and that human tissue is equivalent to a resistance with relatively high shunt capacitance. These characteristics are believed to influence the response to minimal shocks.

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Although dealing mainly with characteristics of living tissue as an electrical conductor, the experimental data presented here are part of a much broader study of the physiology of fatal electric shock. The basic electrical characteristics of living tissue dealt with here are of fundamental importance in interpreting the effects produced by electricity, especially in regard to the frequency, intensity, and duration of the current applied.

Although the response of living tissue to current impulses of various intensities and durations has been studied extensively by other workers in this field,[1–14] actual numerical values of applied current and voltage have not been determined exactly, because of inadequacy in apparatus. Moreover, the influence of the electrical characteristics of the tissue upon response has not been fully investigated. The present paper deals with a study of both these features. It presents the results of: (1) an investigation of the quantitative relation of current intensity and duration in producing response; and (2) a study of the electrical characteristics of living tissue as a conductor.

General Method

In studying the electrical characteristics of living tissue, a current wave of rectangular shape was applied to the tissue and the accompanying voltage wave was recorded. The essential characteristics of the tissue as a conductor were estimated from the shape of the voltage wave. The numerical values of the constants involved were obtained by passing the same current impulse through a suitable circuit—an equivalent circuit—containing the necessary capacitance and resistance to permit duplication of the voltage wave.

The use of a rectangular wave of current in studying the electrical characteristics of tissue as a conductor has certain advantages over the use of sinusoidal alternating current as employed by previous workers:[15–17] (1) With sinusoidal current it is necessary to make a series of determinations at different frequencies before the analysis of the conductor can be made to establish its equivalent circuit; (2) the electrical response of living tissues customarily is studied in respect to single shocks, and therefore a method that establishes the electrical characteristics for single shocks can be employed simultaneously with such studies; and (3) the effects produced by polarization are taken into account to the extent that they occur under these conditions.

Since none of the circuits previously reported[1,14,18–20] for supplying electrical impulses has been capable of furnishing to tissue that is not purely resistive an exactly rectangular current wave throughout the range of currents and durations desired, a special circuit was developed for this purpose.

Apparatus for Supplying Impulses

This circuit, the diagram of which is shown in figure 1, fulfills the following requirements: (1) It provides a current of rectangular wave shape, irrespective of the nature of the electrical impedance of the tissue to which the current is applied; (2) it allows exact regulation of intensity and duration of the current waves; and (3) it affords a means of recording photographically the intensity, duration, and wave shape of either the current or the voltage.

In this circuit a 5 element vacuum tube, the pentode P, operated on the saturated portion of its characteristic, maintains a constant flow of current regardless of the variation of voltage across the tissue at Z to which the current is applied. The tissue, the pentode P, and 2 batteries are in series when the shock is administered. The amount of current from anode to cathode, and hence through the tissue, is determined by the potential imparted to the screen and control grids of the pentode. For sufficiently high voltages on the plate of this pentode, the variations in the impedance of the circuit, including the tissue, produces virtually no change in current.

The duration of the impulse is controlled by 2 gas filled triodes, T and T_1, which operate as switches to start and indirectly stop the flow of current. On pressing the key K, the grid potential of T_1 starts to rise at a rate determined by the resistance R_6 and the capacitance C_2. When the voltage on the grids reaches a definite value the tube T_1 suddenly becomes conductive, allowing a potential to be imparted to the

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grids of the pentode P and the current to flow through the tissue at Z.

The use of the gas-filled triode in starting the flow of current rather than the key K serves 2 purposes: (1) Irregularities in the current wave due to arcing and chattering at the mechanical switch are avoided; and (2) the brief but definite time elapsing between the closing of the switch and the flow of current through the triode allows the cathode ray spot of the oscillograph—started by the key K—to move a short distance from the starting point before the voltage wave is recorded. Fogging from the stationary spot thus is avoided, and a clearer photographic record is obtained. The time elapsing is controlled by the capacitance C_2 and the resistance R_6. The resistor R_5 serves to load tube T_1 sufficiently so that the voltage across the tube is nearly independent of the current passing through it.

The flow of current through the tissue at Z is stopped by a second gas filled triode T, the operation of which is controlled by the resistance R and the capacitance C. On becoming conductive this tube, as arranged in the circuit, causes a sudden decrease in the potential applied to the grids of the pentode P rendering the tube nonconductive; the flow of current to the electrodes thus is interrupted.

The time interval between the starting of T_1 and T—the period during which the current flows through the electrodes—is that required for the voltage across capacitance C to build up from zero to a definite value depending upon the tube and circuit constants. This voltage is given by the equation

$$e = E\left(1 - \epsilon^{-\frac{t}{RC}}\right)$$

where E is the voltage across R_5. If the value of e required to make tube T_1 conduct is e_0, then the time required for e to reach this value is

$$t_0 = RC \log\left(\frac{E}{E - e_0}\right)$$

Hence the time duration of the impulse is directly proportional to the resistance R. By using a decade box for the resistance R it becomes a simple matter to obtain current impulses of precise and predetermined duration.

The intensity of the current applied to the electrodes is controlled by the potential applied to the grid of the pentode P. This current may be determined either before or after the impulse is applied by placing switches S_2 and S_3 in position a, opening S_1 and closing key K. By this procedure both the electrodes and the anode of tube T are disconnected and an uninterrupted flow of current passes through the milliammeter A. Since the pentode P always is operated on the saturated portion of its characteristic, the current thus measured is the same as would flow through the electrodes with the same setting of the slide-wire rheostat R_1.

The cathode ray oscillograph used for recording wave shape, intensity, and duration of voltage is connected as shown in figure 1. The horizontal plates are connected across C_1 which is connected in series with P_1. When key K is closed, C_1 is charged at a uniform rate and thus the oscillograph beam is given a constant horizontal velocity. Switch S_5 is used to connect the vertical deflecting plates of the oscillograph to either a 1,000 cycle oscillator to determine the horizontal speed of the beam, or to the amplifier. A photographic record of the moving spot is obtained on the film of a camera focused on the screen.

When the switch S_2 is in position b and switches S_3 and S_6 are each in position a, the electrodes are in series with the resistor R_3 and the input to the amplifier is connected across the electrodes. The input impedance to the amplifier is sufficiently high so that the current it draws is negligible. The vertical deflection of the oscillograph beam is proportional to the voltage across the tissue.

When S_2 is in position a and S_3 is in position b the electrodes are in series with the resistor R_4 and the input to the amplifier is connected across R_4. The vertical deflection of the oscillograph beam is then proportional to the current through the tissue. The oscillograph is calibrated by means of the variable resistor R_4 and ammeter A.

Figure 2 shows the current wave shapes recorded with the complete circuit as described. Each of the waves shown is for a time setting of 0.006 second and

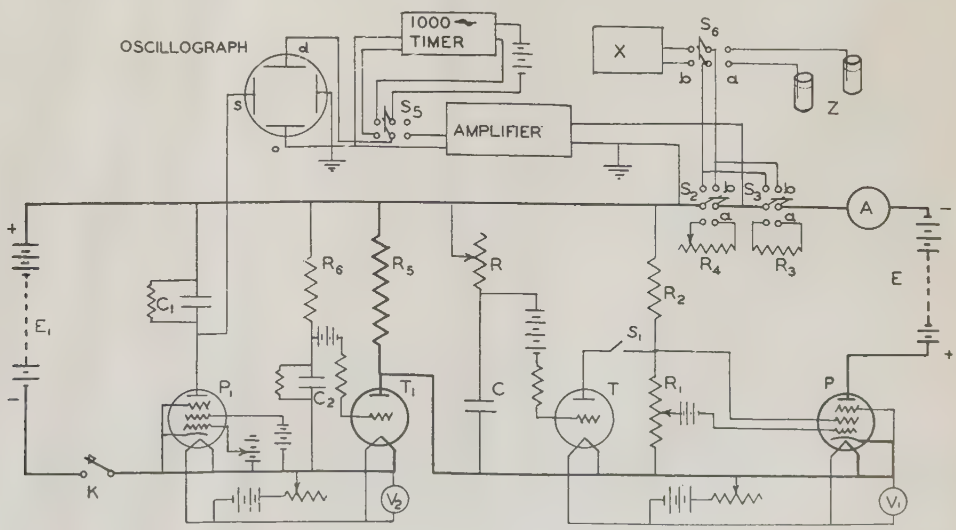


Fig. 1. Circuit diagram of equipment for applying a current of rectangular wave shape to living issue

a current of 2 milliamperes. Wave a was obtained with a resistance of 100 ohms across the electrodes and wave b with a resistance of 10,000 ohms in parallel with a 0.8 microfarad capacitance. It may be observed that the shapes, heights, and durations of the current waves, are unaffected by this change in the impedance between the electrodes.

Such changes in impedance, however, do alter the shape and height of the voltage wave recorded during

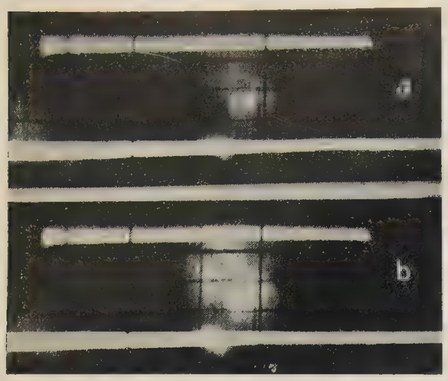


Fig. 2. Current waves with (a) 100 ohms in electrode circuit, and (b) 10,000 ohms in parallel with a capacitance of 0.8 microfarads in the electrode circuit; 2 milliamperes for 0.006 second

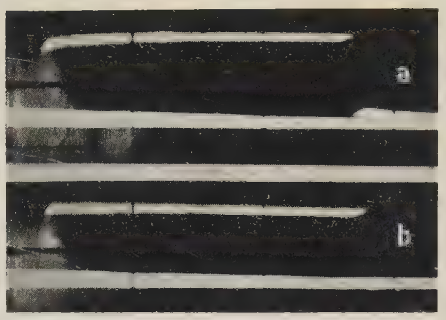


Fig. 3. Voltage wave produced by a rectangular current wave of 1 milliampere for 0.006 second on (a) a frog and (b) a 900 ohm resistor

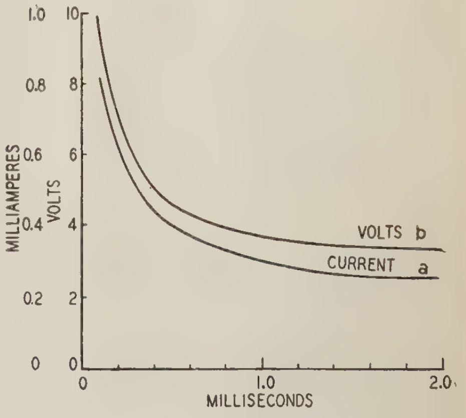
the passage of the rectangular current wave. From the wave shapes of the voltage it becomes in turn possible to determine equivalent electrical circuits that have similar impedance characteristics. While it is possible to obtain the constants of the equivalent circuit by calculation, it is convenient to determine them by a substitution method in which the voltage wave shape corresponding to the rectangular impulse through the tissue is compared with the voltage wave obtained when a circuit combination is substituted for the tissue. The shape of the voltage wave indicates the appropriate circuit and a few trials usually suffice to obtain the correct magnitudes for the circuit elements. Moreover, this substitution method seems preferable to one based upon calculation because any errors in the amplifier or oscillograph, such as nonlinearity, are effectively cancelled.

Electrical Characteristics of Frog Tissue

Current impulses were applied to the intact frog or human tissue by means of saturated salt solutions connected to the circuit through platinum electrodes each having a total surface of 16 square centimeters. A series of tests indicated that it was unnecessary to use a more elaborate arrangement of electrodes, since these, when bridged by a platinum strap, showed no voltage drop upon passage of the impulse currents. The use of copper, bronze, or other metal for electrodes, or the use of platinum in dimensions smaller than those employed, introduced errors.

In applying current to frog tissue the pithed animal was suspended so that its rear legs were immersed in the saline solution to within 1.5 centimeters of their junction. Within 5 minutes, usually less, the resistance, which diminished slightly at first, became constant. This resistance was determined by applying at frequent intervals impulses of equal current intensity. The first few impulses produced higher voltage waves than those of succeeding shocks; but as the resistance became constant the voltage waves obtained were of constant height. While the resistance could be calculated from the height of the voltage wave in relation to the current applied, it was found more convenient, as

Fig. 4. Time-intensity relation of current impulses required to produce minimal responses in frogs' legs (unskinned) and peak voltages developed



already noted, to observe the height of the voltage wave against a calibrated screen and match it in height with a voltage wave produced by passing the current through a known resistance inserted at X by throwing switch S_6 to position b (figure 1).

The resistance found on frogs thus studied ranged between 700 and 1,300 ohms. Since these resistances were decidedly lower than those found on human beings, the possibility that the frog's skin might be responsible for the differences led to the determination of the resistance of the skinned legs immersed to the same area. It was found that the skinned legs had approximately twice the resistance possessed by the unskinned legs. This indicates that frog's skin is a conductor of lower resistance than the underlying tissues. An opposite result was obtained in a similar experiment performed on a rat; moreover, in human beings needles inserted beneath the skin gave much lower values of resistance than those obtained with electrodes of comparable size applied to the surface of the skin.

The shape of the voltage wave obtained for a current of 1 milliampere and a duration of 0.006 second on the intact frog's legs is shown in figure 3a. The rectangular shape of the wave indicates the absence of any appreciable capacitance. Curve b, figure 3

shows a corresponding voltage wave produced by an impulse of the same intensity and duration applied through a resistance of 900 ohms. The similarity of these curves indicates that from the standpoint of its total impedance frog tissue can be considered to have negligible capacitance.

Further experiments were conducted on the frog to determine the relation between intensity and duration of current required to produce minimum muscular response. The data from one such series of determinations is shown as curve *a*, figure 4. The peak voltage required to produce these responses is shown by curve *b*, figure 4. It will be observed that these peak voltages vary in approximately the same ratio as the current producing them; as may be seen later, a quite different result was obtained on human tissue.

Electrical Characteristics of Human Tissue

In applying the current impulses to human tissue the first and second fingers of one hand were immersed in the saline solution to an extent corresponding approximately to the immersed area of the legs of the frog used in the previous experiment.

Repeated experiments indicated that the steady state resistance was not reached until 15 to 40 minutes had elapsed. On 6 subjects the resistance averaged 7,100 ohms.

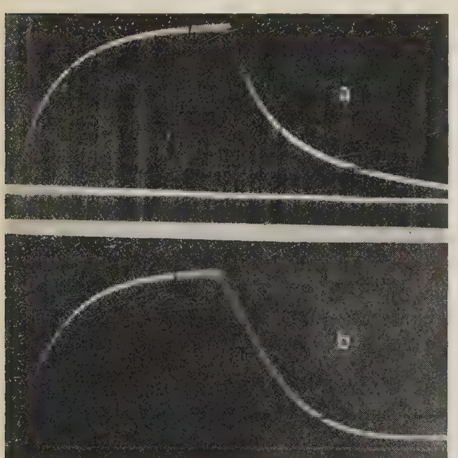


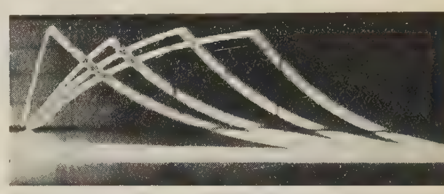
Fig. 5. Voltage wave produced by a rectangular current wave of 0.2 milliampere for 0.006 second on (a) human fingers and (b) a 19,500 ohm resistance in parallel with an 0.08 microfarad capacitance

A voltage wave produced across human fingers by a current of 0.2 milliampere for 0.006 second is shown in figure 5*a*. The shape of this curve is distinctly different from that obtained with the frog. It indicates the presence of considerable capacitance. Figure 5*b* shows a curve obtained with the same current wave applied to an equivalent circuit consisting of a resistance of 19,500 ohms shunted by a capacitance of 0.08 microfarad.

The relationship between current and duration of impulse required to produce minimal response of human tissue was studied on 5 different subjects with a total of 114 determinations. In each case a constant depth of immersion of the fingers in the solution was maintained and determinations were made only after a steady state of resistance had been reached. In determining the current required to produce minimal responses, impulses of the desired duration were sent through the fingers at frequent intervals; the sliding contact of the resistor R_1 was adjusted gradually between impulses so that the successive impulses became stronger. The subject, who could not see the key being opened or closed, was asked to indicate each time he felt a shock. The current then was varied up and down until the minimum current required to produce sensation was definitely established.

The intensity-duration curves for current thus obtained from the 5 subjects are shown in figure 6. It is evident that for any one duration of impulse there is considerable difference in the current intensity required to produce the minimum response in the different subjects. For each subject, however, the current intensity required for response at each duration is quite constant; repeated determinations over intervals of several days indicate a maximum variation of 6 per cent. The current waves of figure 6 are similar to the curves reported by other investigators[1–14] and contribute little to present knowledge of minimal responses, except that in the experiments reported here the currents and duration are determined accurately and the wave shape of the current impulses is maintained rectangular.

Fig. 7. Voltage wave for minimal response produced by current impulses of various durations



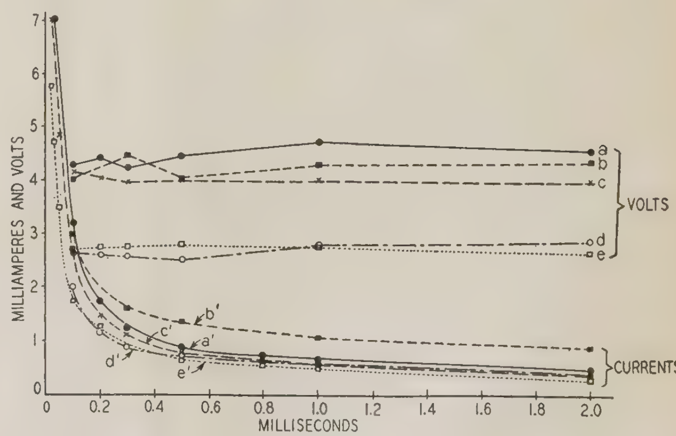


Fig. 6. Time-intensity relations of current impulses required to produce minimal responses in human fingers, and peak voltages developed

In obtaining the intensity-duration curves shown in figure 6, the voltage wave of each impulse was recorded photographically from the oscillograph. The curves for peak voltage (figure 6), it may be noticed, are distinctly different from those obtained for frog's tissue. For the frog the curve of voltage followed proportionately the curve of current.

For human tissue the peak voltage was constant for any combination of current and time that produced a minimum sensory response.

Figure 7 shows the voltage waves produced by a series of impulses of various durations each causing minimal response. The uniformity of the voltage peak can be observed.

As previously observed, similar voltage measurements made when current was applied to the legs of the frog to produce minimal motor response did not show this same constancy of peak voltage. The same findings appeared when the current was applied directly to the nerve. Figure 8 shows the intensity-duration relation for current required to produce minimum motor responses with electrodes applied to the sciatic nerve of a frog's leg; it also shows the corresponding peak values of the voltage waves.

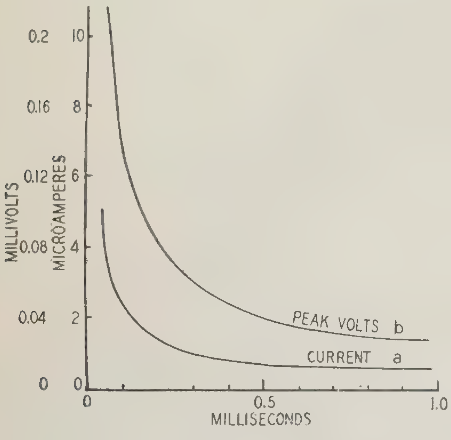


Fig. 8. Time-intensity relation of current impulses required to produce minimal responses in a frog's nerves, and peak voltages developed

The differences thus found in the response of frog and human tissues to rectangular current impulses may result from differences in the nature of the impedances of the tissues. Human tissue has a high capacitance and its approximate equivalent circuit consists of a capacitance connected in parallel with a resistance, as shown in figure 9*a*. The approximate equivalent circuit for living frog tissue is shown in figure 9*b*. The series resistance is about 10 times the parallel resistance. These proportions make the equivalent circuit of the frog very similar to a pure resistance.

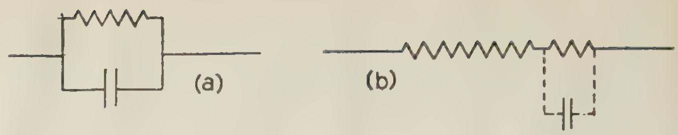


Fig. 9. Characteristic equivalent circuits of (a) human tissue and (b) frog tissue

In the circuit (b) for the frog tissue, the capacitance is in parallel with only a small portion (10 per cent) of the total resistance, thereby making the circuit approximately resistive

Summary

1. An apparatus is described by means of which a rectangular wave of current of any desired duration and intensity can be applied to living tissue.

2. The apparatus includes a cathode ray oscillograph by means of which the intensity of the current and the wave shapes of the current and voltage can be recorded photographically.

3. By means of the apparatus it is possible to analyze the electrical characteristics of living tissue, determine the impedance, and establish analogous circuits.

4. Frog tissue shows virtually no capacitance; human tissue shows a high capacitance.

5. These characteristics of living flesh are believed to influence the time-intensity relations of response to minimal shock. In the frog the curve obtained for the peak of voltage for shocks of various intensities and durations producing minimal responses (motor), corresponds closely to the curve obtained for the current. In human beings (sensory response) this relation does not exist; for all times measured the peak of voltage was constant irrespective of current intensity required to produce response.

6. In the determinations of minimal response, the actual values of current and voltage applied are given.

7. These studies emphasize the fact that the data obtained from electrophysiological studies of frogs cannot be interpreted as applying directly to human beings.

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Dial Switching of Connecticut Toll Calls

The special application of step-by-step dial switching equipment to the handling of short distance toll telephone traffic was introduced in Connecticut in 1929, and has been extended gradually until at present approximately 46,000 toll messages per day, comprising 70 per cent of the traffic between exchanges in this area, are dispatched over the 1,367 circuits of the dial switching network. The resulting service improvements and savings in operating efforts are discussed in this paper, and a brief description of the transmission and equipment characteristics of the system is given.

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THE dial switching, or dial tandem,[1] system for handling short distance toll calls may be described as an arrangement of step-by-step dial selector groups located at various centers about an area, connected with suitable trunk circuits to one another and to the switchboards and dial terminal equipments of the associated telephone exchanges. The operators at these switchboards actuate the selectors by dialing to complete calls from their subscribers to subscribers in other exchanges and thereby obtain a direct connection to the subscriber terminal in dial exchanges, or through operators at local switchboards in the manual exchanges. The connections may involve only one interexchange toll circuit unit, or they may require the end-to-end or tandem linking of 2 or more circuit units to establish the traffic path; the latter is made by the dial equipment without the assistance of intermediate operators. In addition, through supervision is given to the originating operator, the removal and replacement of the receiver of the called subscriber being shown by means of lamp signals.

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1. For all numbered references, see list at end of paper.

The application of step-by-step dial equipment to the switching of toll calls is of rather recent origin, having been introduced for the first time on any considerable scale in 1926 in the territory in and about Los Angeles, Calif.[2]

In Connecticut, telephone subscribers served by manual switchboards are requested to give all station-to-station toll calls to the local operators, and all person-to-person calls to the toll operators. The local operators complete these calls over the tandem system where possible, or over direct ringdown trunks to other local switchboards. If no such routes are provided, the calls are passed to the toll operator for handling over the toll ringdown circuit network. In dial areas, both station-to-station and person-to-person calls are given by the subscriber to a common group of operators located at toll type switchboards, who use the tandem system for completing all types of calls to the exchanges for which tandem routes are provided.

Dial tandem switching of toll traffic is particularly suitable in densely populated areas having a considerable amount of short distance toll traffic, and where much of this traffic terminates at dial subscriber stations. Conditions in Connecticut satisfy these essentials with an area of approximately 4,800 square miles and a population of more than 1,600,000 inhabitants reasonably well distributed over the territory. The greatest air line distance between telephone exchanges in the state barely exceeds 100 miles. In the 75 telephone exchanges operated by The Southern New England Telephone Company and independent connecting companies, about 66,000 out-of-town telephone messages destined for subscribers in Connecticut or certain near-by exchanges in adjoining states orginate during every business day. At the present time 11 of these 75 exchanges are served by dial equipment of the step-by-step type, and the remainder is served by manual switchboards of various types. The dial equipment generally is found in the large exchanges, and it provides telephone service for approximately 57 per cent of the subscriber stations in the area. Only 5 of the 75 exchanges serve more than 10,000 telephone stations each, and the largest exchange (Hartford) serves less than 60,000 stations.

Background

The introduction of the dial tandem method in Connecticut was not forced by the trunking problems commonly encountered in the larger metropolitan areas. It was introduced as an improvement in method, and was economically adopted at the time of general replacements accompanying an extensive program for dial conversion of manual telephones.

Comprehensive studies comparing the dial tandem switching plan for handling short distance toll traffic with the former ringdown circuit methods, and also with a plan involving the then relatively new straightforward trunking equipment[3] on a direct trunk basis, indicated service benefits and over-all savings favoring the dial tandem plan. It was decided, therefore, to introduce this plan gradually as the larger exchanges were converted to dial operation.

Short distance toll traffic formerly was handled

by 1 of 2 distinct methods. The first, or local-operator direct-circuit method, was used for station-to-station calls where the amount of traffic could justify direct circuit groups of the ringdown type between local switchboards of different exchanges. Before the introduction of the tandem system, approximately 78 per cent of the short distance toll traffic was handled by this method, which is shown in figure 1. In this typical case the local operator in New Britain (a manual exchange), on receiving a call for a subscriber station in Middletown (a manual exchange), connected the calling subscriber to one of the direct ringdown circuits to that local switchboard and signaled the Middletown operator by ringing. The New Britain operator passed the number of the called station to the Middletown operator, who completed the connection. Both operators received lamp signals from their subscribers denoting the end of conversation.

The second or toll board method was employed by toll operators for those station-to-station calls to exchanges to which the local operators had no direct circuits, and for person-to-person calls. In an example of one variation of this method, shown in figure 2, the New Britain local operator received a call from one of the local subscribers to Manchester, also a manual exchange, and dispatched it over a recording trunk to a New Britain toll operator, to whom the subscriber gave his own number and the number of the desired Manchester subscriber station. The New Britain toll operator, using a second cord, then plugged into an idle ringdown toll circuit to the Hartford toll board, which is the toll center for Manchester. The New Britain operator rang, and on answer of the Hartford toll operator, gave the desired Manchester station number. At the same time, over a call circuit, the New Britain toll operator requested an operator at another position of the New Britain local switchboard to plug an idle toll switching trunk into the multiple jack of the calling subscriber's line, and connected the second cord also to this trunk, both operators releasing the first connection to the recording trunk. The Hartford toll operator in the meantime connected the toll circuit through another toll switching trunk to the Manchester local switchboard, where a local operator completed the connection to the called subscriber's line, and the Hartford toll operator rang the called subscriber's station. It will be seen that 5 operators were required to establish this connection. In many cases direct circuits were not available between toll switchboards, thus requiring another operator at an intermediate toll switchboard to connect 2 toll circuits together for the traffic path and further complicating the establishment and discontinuance of the connection.

Tandem Network

The manner in which these connections are completed through the dial tandem network is indicated in figure 3. New Britain and Middletown remain manual exchanges, but Manchester has been converted to dial operation. The New Britain local operator answers a subscriber in the usual manner, receives a call for a Middletown station, and connects the subscriber to a trunk terminating at a selector in the Hartford tandem center. The New Britain operator then takes the single ended dial cord with which the position is equipped, plugs it into the dial jack associated with the trunk, and dials the digits 41, previously established as the code for Middletown. The tandem first selector[4] steps to the fourth level and is connected to a tandem second selector that steps to the first level and selects an idle trunk terminating in completing equipment of the jack ended straightforward type at the Middletown switchboard. The Middletown local operator receives a lamp signal when the trunk is seized, and answers with a local cord modified for tandem use, automatically sending an order tone to New Britain. The Middletown operator then receives the called

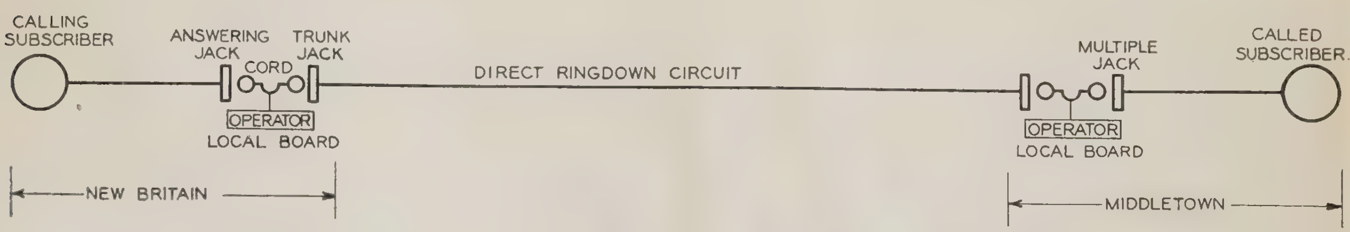


Fig. 1. Diagram illustrating local-operator direct-circuit method of handling short distance toll traffic

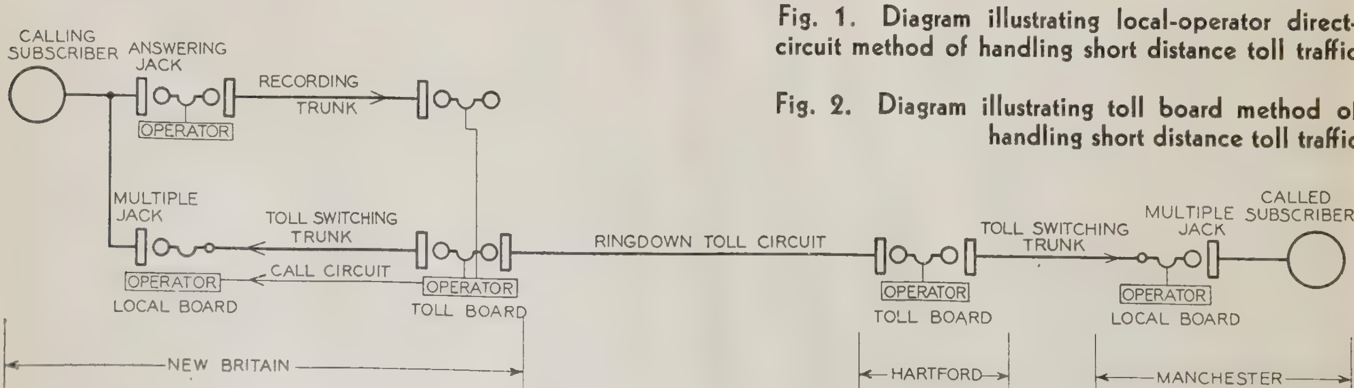
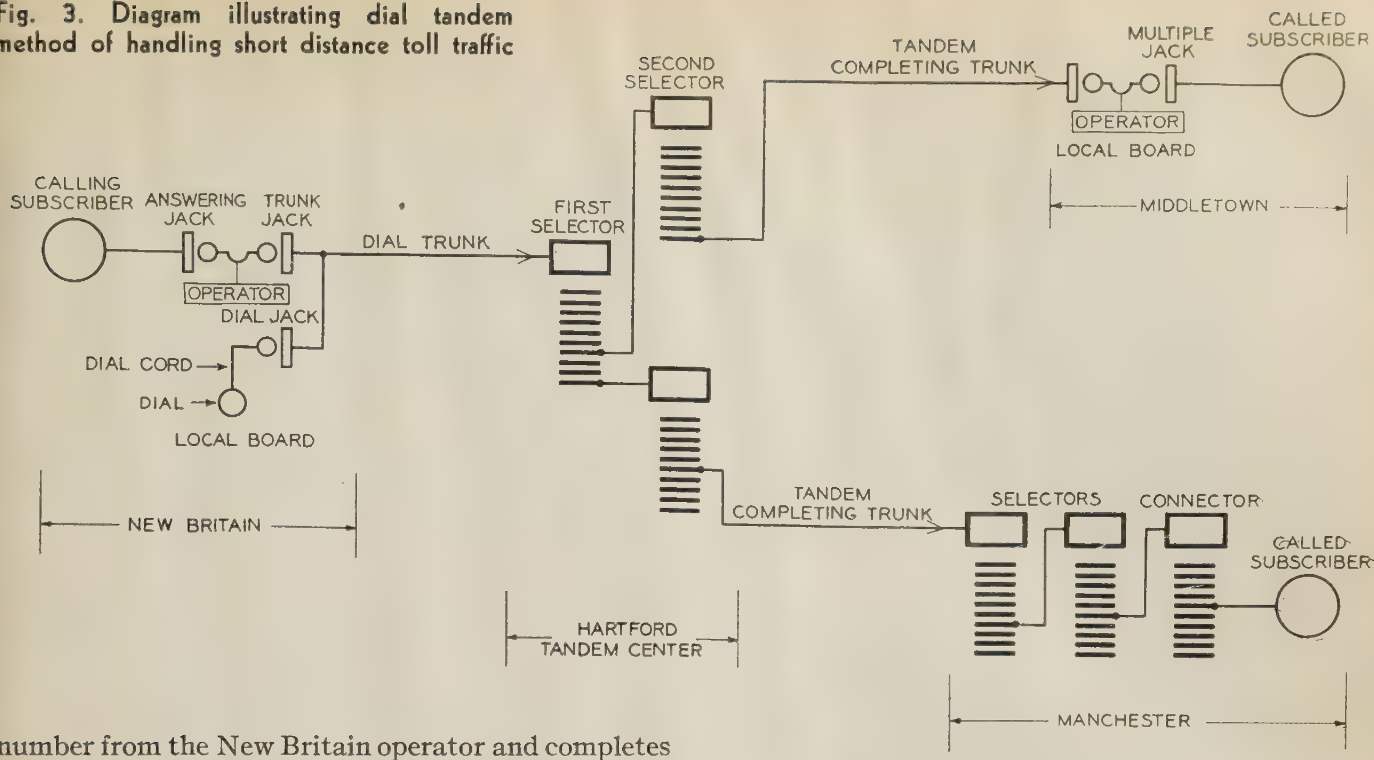


Fig. 2. Diagram illustrating toll board method of handling short distance toll traffic

Fig. 3. Diagram illustrating dial tandem method of handling short distance toll traffic



number from the New Britain operator and completes the call to that subscriber's line, ringing the called station. The answer of the called subscriber extinguishes a lighted lamp associated with the New Britain operator's cord. The end of conversation is indicated by the lighting of both lamps associated with the New Britain operator's cord, and the connection is broken, releasing the interoffice circuits and automatically signaling the Middletown operator to disconnect her cord. A busy condition of the called subscriber's line is indicated to the calling operator by a tone and visual flashing signal. The number of operators (2) involved in this call is the same as under the previous local-operator direct-circuit method, but circuit economies have been realized by the discontinuance of the New Britain-Middletown direct circuit group.

If the call had been for a subscriber in the Manchester dial office, the procedure would have been the same, except that the New Britain operator would have dialed the code 15 to select a trunk to the Manchester office, followed by the digits of the subscriber's number, in this case 15-4567, and the dial equipment would have completed the connection with only one operator having been involved. A lamp associated with the New Britain operator's cord would be extinguished when the Manchester subscriber answered, and both cord lamps would be lighted again at the end of conversation. A busy condition would be indicated to the New Britain operator by a tone signal and a flashing cord lamp.

The opportunities afforded for faster and somewhat more accurate service and improved economy of operation by the dial tandem method in comparison with the local operator direct circuit and toll board methods may be perceived readily.

The present scope of the Connecticut tandem system is shown in figures 4 and 5. Figure 4 shows all telephone exchanges in Connecticut and indicates the tandem switching toll centers, other toll centers, and the remaining local offices of the toll tributary class. Trunk circuit groups of the tandem system are shown. It should be noticed that in many instances the tandem centers are connected by groups of trunk circuits of 2 grades, that is, terminal and "via," the terminal grade being used for the shorter calls, and the "via" grade being used for those longer calls for which transmission considerations require a low loss circuit. The principles controlling the use of these 2 grades of intertandem trunks will be developed later in this paper. It is expected that all exchanges in Connecticut eventually will be connected to the tandem system.

The dial selectors of the tandem network are located in dial equipped exchanges at natural switching points throughout the area, where indicated by junctions of the interexchange wire routes and the general pattern of toll traffic flow.

Figure 5 shows the entire tandem system, including the arrangements of the switching selectors in the tandem centers and the assigments of the levels of the switch banks to the various trunk groups. First and second selectors provide sufficient flexibility of codes for the offices of the system.

The following examples of codes assigned to the Watertown office associated with the Waterbury tandem center indicate the paths used for a few representative calls:

Watertown to	Code	Digits of Dial Subscriber's Number
Bristol	74	+ XXXX
Fairfield	8596	
New London	296	+ XXXX or 2-XXXX
Orange	240	
Rockville	948	
Southington	13	
Stamford	870	+ 3-XXXX or 4-XXXX
Willimantic	8686	

Traffic Considerations

From the operating viewpoint, the dial tandem plan offers definite advantages of faster and somewhat more accurate service, and savings in operating effort.

The following is a summary of the Connecticut short distance toll traffic handled by the several operating methods, comparing the period just before the introduction of the dial tandem plan with the present extent of tandem operation:

Method of Handling	Per Cent of Short Distance Traffic Handled	
	Pretandem	Present Tandem
Local operator direct circuit	78	20
Toll board, ringdown circuit	22	10
Tandem, local and toll boards	0	70

In 1928, before the introduction of dial tandem handling, the indicated interval from the receipt of the calling subscriber's signal at the toll or local switchboard to the start of conversation averaged 70 seconds for all toll calls. This average included the longer and more involved out-of-state calls as well as the short distance toll traffic. Under the present trunking arrangements this average interval has been reduced to 54 seconds. One important factor in this decrease is the direct handling by the local operators, over the tandem facilities, of much of the traffic that formerly required the toll board method; another is the use of the tandem facilities on much of the traffic handled at toll boards.

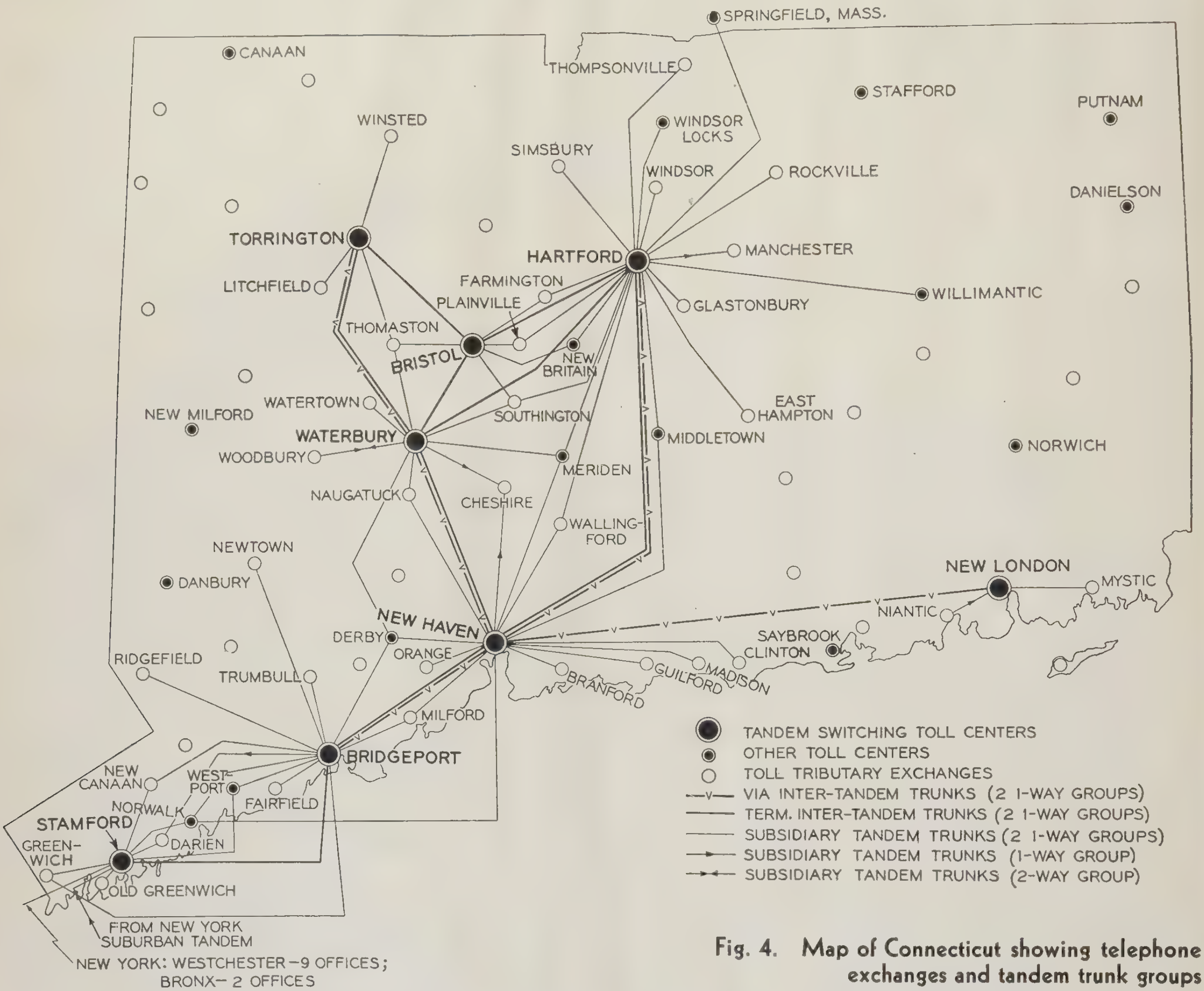


Fig. 4. Map of Connecticut showing telephone exchanges and tandem trunk groups

The theoretical speed of dial tandem operation, from the receipt of the calling subscriber's signal at the switchboard to the first ring on the called line, is 16 seconds for a call from a manual office to a subscriber in a connected dial office, and 20 seconds from a manual office to another manual office equipped with the cord ended straightforward type of tandem completing trunks. These intervals will vary slightly, depending on the number of digits of the tandem code. In applying these latter figures to actual traffic, it must be remembered that they do not include the time from the first ring on the called

line to the answer of the called subscriber, which usually is an appreciable interval.

Greater accuracy is obtained by the reduction in the number of operators required in dispatching a call, with fewer possibilities for human error.

Marked savings in operating effort with the tandem plan are apparent from the comparison made earlier in this paper of the tandem operating method with the local-operator direct-circuit and toll board methods. Savings are realized particularly where calls formerly requiring toll board handling now can be handled by the originating operator over the tandem network, and where that operator can dial directly to a called subscriber terminal in a distant dial office.

The composite effect of tandem operation on the interexchange circuit network has been a slight increase in the number of circuit groups and also in the total number of circuits, assuming a common level of traffic. Various circuit economies have been possible with the tandem plan, but these have been overbalanced by the substitution of one-way tandem circuits, over which calls can be advanced in only one direction, for the former 2-way ringdown circuits. The one-way groups in the system are rather small, few exceeding 10 circuits and many having only 3 or 4; consequently, the requirements of these groups for the desired probability of available traffic paths have resulted in the total of circuits in the 2 one-way groups between an office and the tandem center exceeding the circuits in the replaced 2-way group. Circuit terminal equipments providing for 2-way tandem operation are now under consideration, and they may be used more generally in the future. These equipments relatively would be more expensive than the one-way equipments, but their

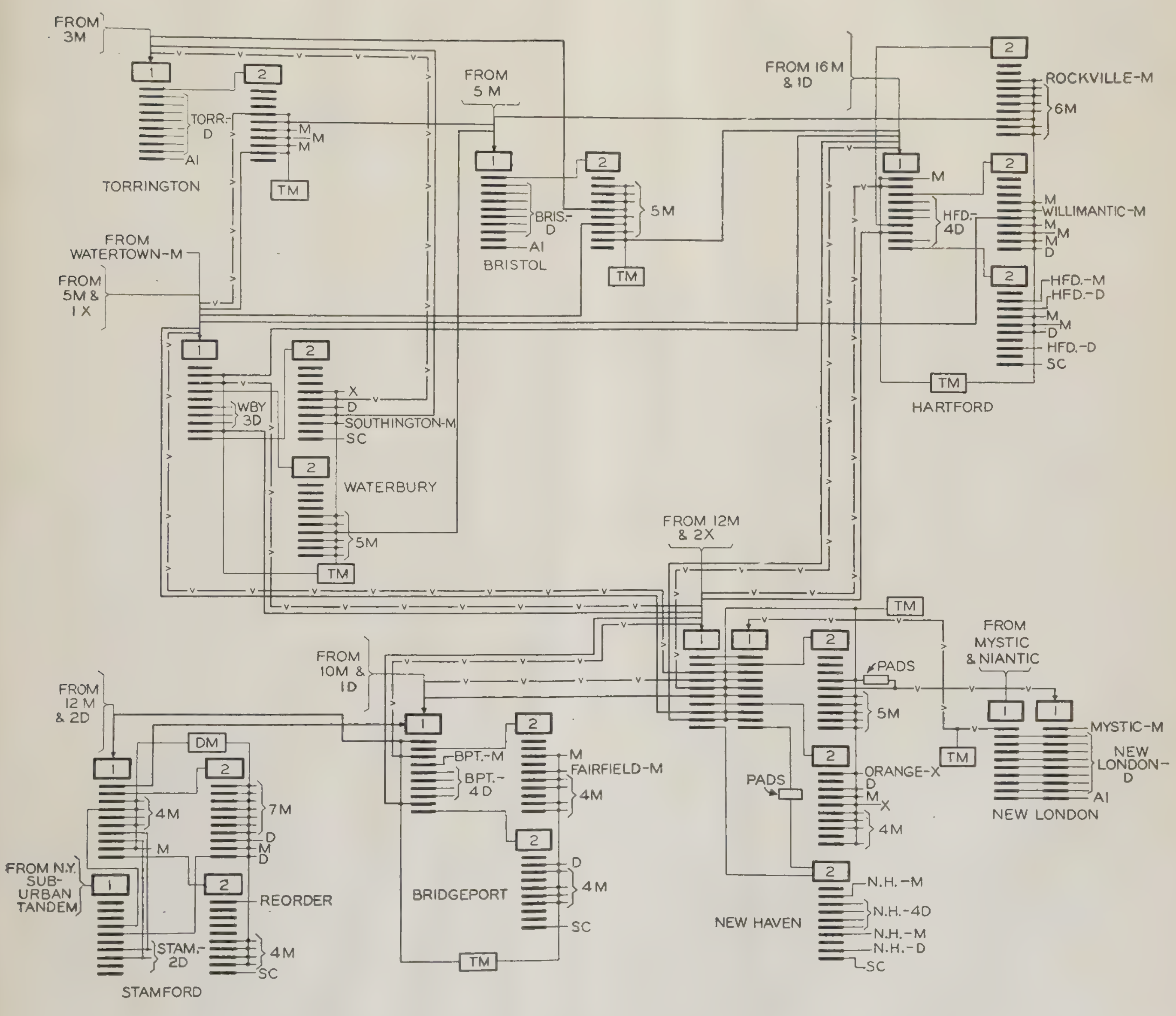


Fig. 5. Schematic diagram of entire dial tandem system in Connecticut

D—Step-by-step dial office
M—Common battery manual office
X—Magneto office
1—Tandem first selector
2—Tandem second selector
TM—Toll board multiple
DM—Dial "A" board multiple
*A*1—Auxiliary first selector
SC—Service code selector
—v—"Via" intertandem groups
——Terminal intertandem groups

use might be justified particularly where the construction of addition interoffice wire facilities would otherwise be required for the one-way circuits.

The 2-way circuits may be used to supplement the one-way circuits between certain offices, arranged as last choice for the operators involved; the combination affords nearly the same efficiency of circuit usage that is possible with an all 2-way circuit plan.

Another factor increasing the circuits under the tandem plan has been the necessity for providing paths on a more liberal basis for the traffic formerly handled by the toll operators, but which now is completed directly by the local operators. Uniform handling of both out-of-town and local traffic by the local operators, involving the authorization of only one route to each called exchange, requires this more liberal circuit availability.

Circuit economies are found under the tandem plan in the elimination of most of the former direct circuit groups between local switchboards, and of many of the groups between toll switchboards, with the concentration of this traffic on the tandem circuits. Some direct circuit groups have been maintained between near-by local switchboards to avoid uneconomical "back hauling" of traffic. Many of the toll switchboard ringdown circuits between exchanges in the tandem area must be retained also, because toll operators in manual exchanges do not have access to the tandem network.

Other circuit groups discontinued under the tandem plan were those used for the handling of recording traffic from toll tributary offices to their toll centers, where the toll center is also a tandem center. This traffic now is handled over the dial circuits from the tributary office to the tandem center, and the local operator dials a special code to secure a connection from the tandem selectors to the recording operators at the toll board. These toll operators, however, still retain the usual toll switching trunk groups to their tributary offices. It is not practicable to handle this toll switching traffic over the tandem completing trunk groups to the tributary offices, since the tandem circuits do not permit the operator to delay the start of ringing the calling subscriber as required on some calls, or to rering the subscriber.

A considerable reduction in nonproductive circuit holding time is possible with the tandem method, due to the speed with which the originating operator is able to establish even the more involved connections. The automatic release of the equipment following disconnection by the originating operator also effects a saving in circuit usage.

An advantage in administration of interoffice circuit loads is the flexibility that is possible in routing the longer calls over the intertandem groups having the greatest spare capacity, without increasing operating labor or slowing up the service. For example, the operator at the Watertown office, which is connected to the Waterbury tandem center, might dial Rockville through Hartford directly, through Bristol and Hartford, or through New Haven and Hartford, although only one route, the most satisfactory from traffic and transmission standpoints, is authorized. Sometimes it is possible to delay plant additions by rerouting traffic over other channels, if transmission considerations permit. Under emergency conditions, such as cable failure, tandem codes may be changed to allow operators to switch their calls through other tandem centers and so avoid the circuits in trouble.

A special development whereby outgoing trunks from the selectors of a particular tandem center are multiplied at the toll switchboard of that center enables the toll operators to complete calls to those trunks without dialing the one or 2 digits required of operators in the other offices. This has resulted in a saving of operating effort and some improvement in speed of service.

Dials are provided at all switchboards connected to the tandem system, except certain manual switchboards in the Westchester County area adjacent to the Stamford tandem center. Incoming circuits from these few exchanges to the Stamford tandem selectors also appear at the Stamford dial "*A*" board, where the operator is called upon to dial the tandem code (and the called number in the case of a dial office) and then drops out of the connection. The call then is entirely under control of the originating manual operator. This is known as "intermediate dialing."

Very little difficulty has been experienced by operators in dialing the longer combinations of tandem code and dial subscriber numbers, although it is recognized that there may be a practical limit to the number of digits for efficient dialing.

Connections between 2 offices, one of which is not associated with the dial tandem system, are established by the direct circuit method where practicable; otherwise they are established by the toll board method. In no case has the manual connection of a tandem circuit to a nontandem circuit been authorized.

The equipment provisions of the tandem system will not permit the originating operator to recall the operator in a called manual office over the original connection. Where such a recall is required, the originating operator must establish a second connection to the called operator. The called operator can signal to the calling operator by using the flashing recorder circuit where it is provided, or with the flashing facilities of the supervisor's circuit.

Transmission Considerations

The transmission objective for these tandem connections is 23 decibels, which provides transmission of the standard obtaining in the usual very large multioffice exchange. This over-all limit is made up of the 2 tandem terminal losses plus the losses of the intertandem tie trunks. Tandem terminal loss is the sum of the attenuation loss from the tandem center to the outlying central office plus the average of the transmitting and receiving losses between that central office and the limiting subscriber in that exchange.

The intertandem tie trunks of the "via" grade are designed for an operating attenuation of 1.5 ± 0.5 decibels, using a terminal voice frequency repeater permanently associated with one end of each trunk, and 10 decibels is assigned for the tandem terminal

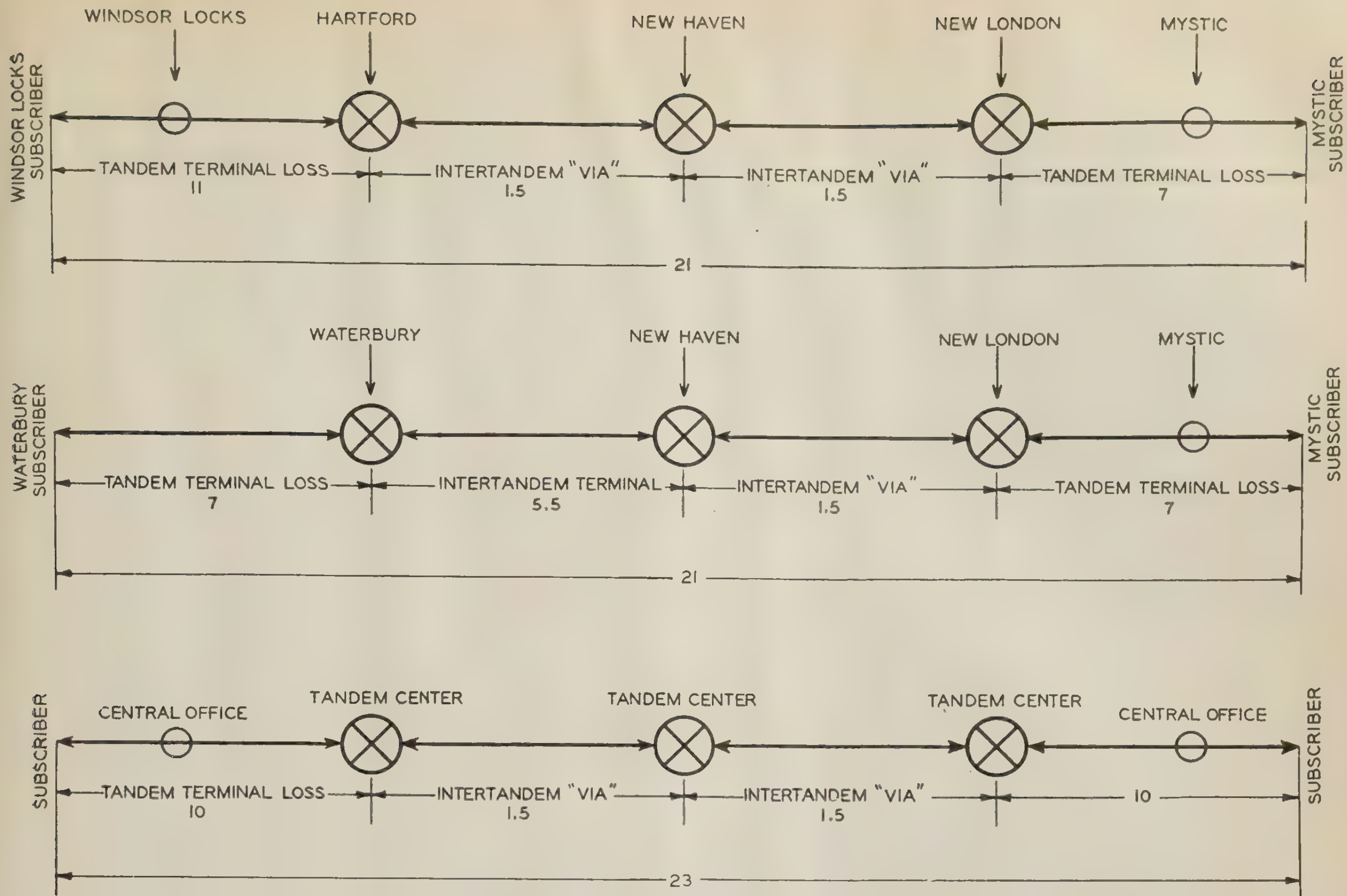


Fig. 6. Diagrams indicating normal transmission objective (bottom) and typical transmission losses (top and middle); losses are indicated in decibels

loss. Normally only 2 intertandem tie trunks are allowed in any connection. As previously pointed out, these very high grade circuits are paralleled by other groups designed for use in terminal connections between the exchanges at the tandem centers, and for such other items as would not exceed an over-all transmission loss of 23 decibels. Figure 6 indicates the normal transmission objective and several actual conditions.

A low grade "via" group consisting of 16 gauge nonrepeatered cable facilities, in addition to the terminal group composed of 19 gauge nonrepeatered cable facilities, was found to be economical for use between Bridgeport and New Haven in switching such traffic as would not be permitted on the 19 gauge terminal group. Each toll connection is studied individually and its routing over the tandem system is approved only if the over-all loss does not exceed 23 decibels. Since the tandem terminal loss for some exchanges at present is less than 10 decibels, it is possible to approve certain items of traffic involving 3 intertandem circuits.

Between New Haven and New London a separate terminal group of trunks cannot be justified. Instead, the "via" group, which operates at a loss of 1.5 decibels on switched connections with a terminal repeater at New Haven, is used also for terminal business. In order to prevent exceeding the allowable crosstalk level, and to provide a safe singing margin on calls involving New Haven subscribers, these circuits are made suitable for terminal traffic by the insertion of a 3 decibel pad on the drop side of the repeaters at New Haven.

It is normal practice in telephone work to use a line and equipment that provide an impedance of about 600 ohms at toll offices; however, the majority of outside facilities used in the tandem system have characteristic impedances of 1,500 ohms, and repeating coils would be necessary in many instances to match the impedances. Since much of the traffic into a tandem center is switched to points beyond its exchange area, the amount of coil equipment required for through connections is minimized by placing the impedance correcting equipment between the 1,500 ohm trunk and the subscriber lines in the local exchange at the tandem center.

It is possible that as the tandem system is extended it will be economical to use the dial-in arrangement of voice frequency repeaters to replace or supplement the terminal repeaters. The advantages of increased traffic capacity allowed by the pooling of a large number of repeaters at each of the centers, and the flexibility afforded for the various types of connections, will compensate for the lower gains occasioned by the use of the dial-in repeaters. Undoubtedly there will be a tendency to reduce the number of different types of loading, and therefore to make possible higher gains with the dial-in repeaters because of better impedance matches between any line and the compromise networks.

Equipment Items

The central office equipment of the tandem system includes selector switches, trunk terminal equipments, operators' switchboards, and voice frequency repeaters.

The selector switches known as toll preceding selectors are similar to the standard local step-by-step selectors used in dial central offices for completing local calls. Certain refinements have been made to provide a visual, as well as audible, busy signal to the originating operators and an arrangement has been introduced for compensating tandem trunks to a standard 1,200 ohm circuit to equalize the fluxes in all pulsing relays to the best condition. Calls are completed to local step-by-step offices through a train of switches designated "*AB* toll," consisting of toll transmission selectors, toll intermediate selectors, and connectors.[5] Toll transmission selectors provide a means of matching impedances between tandem trunks and local subscribers' lines with a repeating coil of proper ratio and a means for supplying battery current more efficiently to subscribers' transmitters. The major functions of the toll transmission selector used for tandem completion are similar to those of a regular toll transmission selector, except that the former causes machine ringing to start immediately without awaiting a ringing signal from

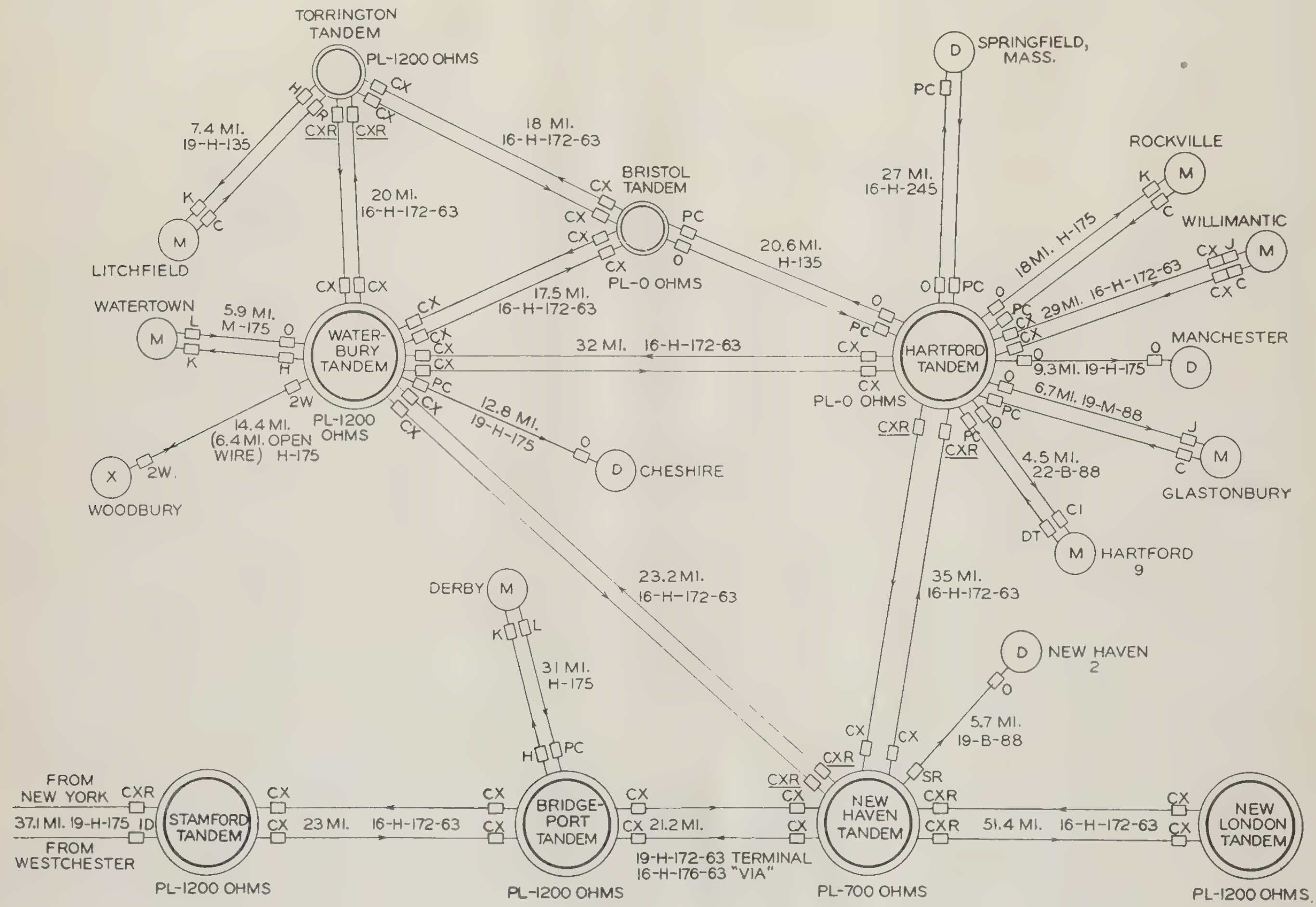


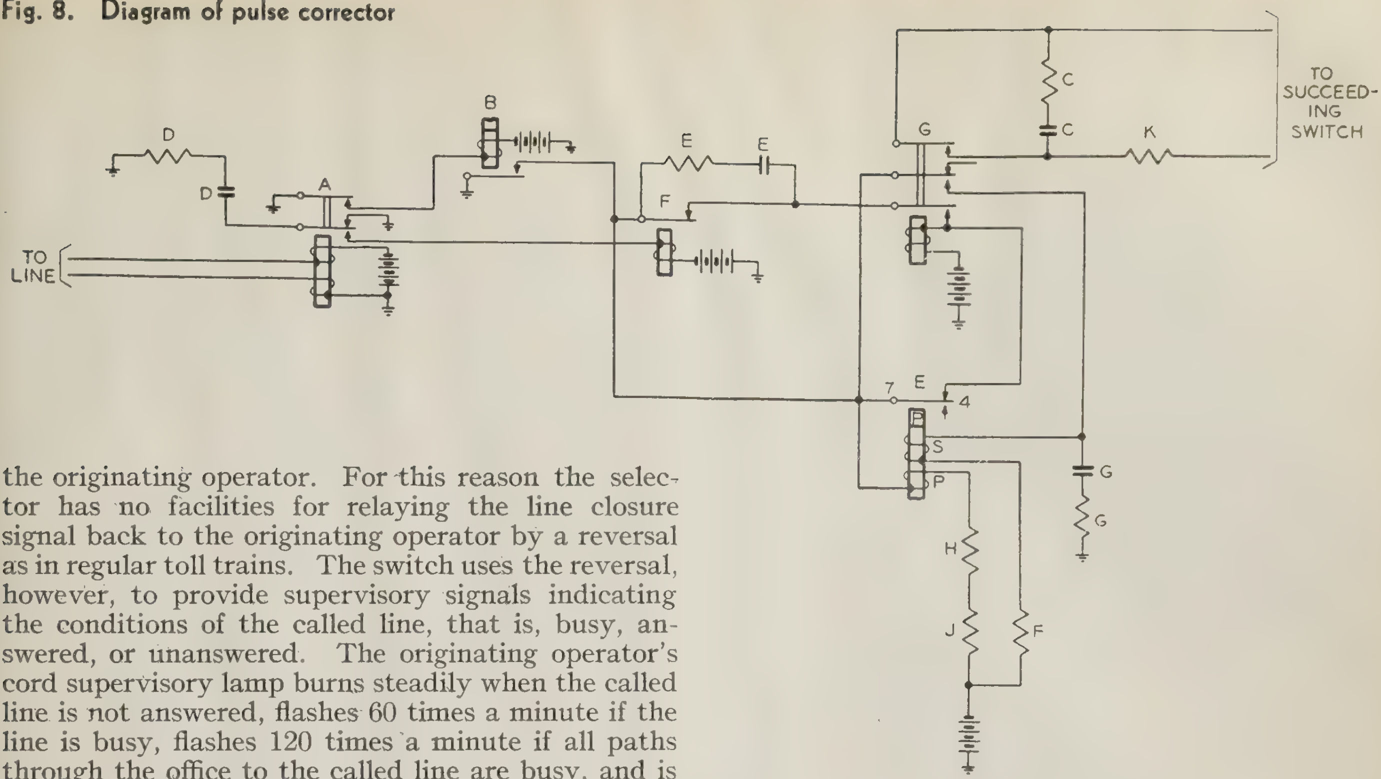
Fig. 7. Typical trunk equipment layout

- *ID*—Intermediate dial trunk equipment
- *DT*—Dial key dial trunk equipment
- *C*—Dial cord dialing trunk equipment
- *J*—Jack-ended straightforward tandem completing trunk equipment
- *K*—Cord-ended straightforward tandem completing trunk equipment
- *PC*—Incoming pulse correctors, 3,000 ohm range
- *O*—No trunk equipment except selectors
- *L*—Listening key dialing trunk
- *SR*—3 wire trunk equipment
- *CX*—Phantom composite equipment
- *CXR*—Phantom composite with repeaters
- *CXR* (underlined)—Phantom composite partially equipped with repeaters for terminal and "via" groups
- *H*—Manual holding equipment
- *CI*—Call indicator trunk equipment
- *R*—Compensating resistances
- *2W*—2-way equipment
- *PL*—Compensated pulsing loop
- *D*—Step-by-step dial office
- *M*—Common battery manual office
- *X*—Magneto office

Average impedance of New London tandem—900 ohms
Average impedance of all other tandems—1,500 ohms

Designations on lines indicate circuit miles, gauge of cable wire, and type of loading, in that order. For example, the designation "17.5 MI, 16-H-172-63" indicates: 17.5 circuit miles; number 16 Brown and Sharpe gauge cable wire; loading coil spacing (H) 6,000 feet (B and M indicate respectively 3,000 and 9,000 foot spacings); inductance of physical or side circuit loading coils, 172 millihenrys; and inductance of phantom circuit loading coils, 63 millihenrys. Absence of the last figure indicates that phantom circuit operation is not used

Fig. 8. Diagram of pulse corrector



the originating operator. For this reason the selector has no facilities for relaying the line closure signal back to the originating operator by a reversal as in regular toll trains. The switch uses the reversal, however, to provide supervisory signals indicating the conditions of the called line, that is, busy, answered, or unanswered. The originating operator's cord supervisory lamp burns steadily when the called line is not answered, flashes 60 times a minute if the line is busy, flashes 120 times a minute if all paths through the office to the called line are busy, and is extinguished when the call is answered.

A considerable variety of trunk terminal equipment is required to meet various traffic, transmission, and outside plant conditions. Some of the required features are phantom, nonphantom, loop or composite signaling, repeatered, nonrepeatered, pulse correcting, pulse repeating, one-way, and 2-way. Figure 7 indicates the actual equipment in use on various typical groups of trunks and also some of the characteristics of each tandem center. The phantom composite method has been outlined in an earlier paper.[2] The more recent improvements include the addition of a pulse correcting feature to the incoming and outgoing terminals of the circuit and a rearrangement of apparatus to allow the use of a relay rack unit, instead of the earlier step-by-step repeater shelf mounting.

The maximum range of circuit at present in use in this area is about 3,520 ohms external loop resistance, or about 35 miles of 19 gauge cable. The longest single link in the system is that between New Haven and New London, a wire distance of about 52 miles, and it has a loop resistance of approximately 2,600 ohms. The development of phantom composite signaling circuits having nearly twice the former range has been completed. These newer circuits may prove economical in combination with smaller gauge conductors and one or more voice frequency repeaters where facility conditions are suitable. The arrangement of apparatus in this circuit more nearly resembles that of the standard ringdown toll circuit terminal equipment by use of separate units for composite sets, phantom sets, composite signaling sets, and auxiliary relay equipment units.

The use of voice frequency repeaters on tandem circuits requires certain circuit arrangements, the most important of which is composite signaling. Since the vacuum tube device must be insulated from direct signaling current, repeating coils are provided in both the physical and artificial lines of the set. Repeating coils block any form of direct signaling current, but the phantom composite signaling circuit provides a method of signaling around repeating coils, and is therefore used whenever voice frequency repeaters are required. Phantom composite sets are universally wired so that they may be arranged for use with or without voice frequency repeaters. Where cable facilities that are not suitable for phantom operation must be used, the phantom composite unit can be modified so that the equipment normally used for the phantom trunk is connected directly to a third pair between offices instead of to the middle point of the side circuit repeating coils. This arrangement is in use between the New York suburban tandem office and Stamford, since nonquadded facilities only are available in a short section of the route. Quadded cable later will permit conversion to the more efficient phantom operation by a minor wiring change at each terminal. In order to avoid singing, and still obtain maximum gain, the voice frequency repeaters must be adjusted for best balance with circuits in the talking position. Since there may be unbalances in the idle and pulsing positions, the phantom composite circuits are arranged for idle termination of both line and artificial line in a resistive and capacitive network. The use of well balanced repeating coils of precise impedance ratio is required with voice frequency repeaters.

The most common type of pulse repeater used in both local systems and earlier tandem service is that in which the pulses received by the line relay are reproduced by its contacts and transmitted to succeeding circuits in the train. This type of trans-

mission is subject to distortion caused by the time characteristics of the relay and the electrical properties of the line facility. Although the total distortion is not serious in a single repetition, the cumulative distortion in several links would exceed the tolerance of the terminating switches and result in wrong selections. To overcome this difficulty a pulse correcting repeater has been developed, which provides a signal of constant length so far as the open period of the pulse cycle is concerned, without regard to the length of signal received.[6]

Figure 8 represents the pulse correcting feature of both loop and composite signaling equipments. During the pulsing interval, the repeater produces outgoing signals approximately one cycle behind the incoming signals. As pulses are received from a preceding circuit they are followed by relay A. When relay A releases on the open portion of the pulse, the capacitor D is discharged. When relay A reoperates on closure of the pulse, relay F operates momentarily on the charging circuit of capacitor D and releases relay G. Relay G, being released, opens the bridge to the succeeding circuit and removes ground from the secondary winding of relay E. The current continues through the secondary winding of relay E to charge capacitor G, but this current gradually diminishes as the capacitor becomes charged. The flux through the secondary winding diminishes gradually until it is less than the flux of the primary winding, and at that time the relay closes contacts 4 and 7. This reoperates relay G, which again closes the bridge to the succeeding circuit. The resistors and capacitors associated with relay E are chosen to provide the time for its release, and in turn the time for the release of relay G, that will give the proper open period to pulse the succeeding switches regardless of the open period received by relay A of this circuit during pulsing.

One feature of most trunk equipments is the provision of a ground on the sleeve circuit of trunks to or from selectors to provide the busy condition for the trunk and a holding circuit for all selectors in the operated position on any particular call. In any one tandem office it is necessary to determine whether the holding grounds should be provided by equipments on each outgoing circuit, or whether a smaller amount of equipment, usually pulse correcting repeaters, will provide a holding ground on each incoming circuit, thus making outgoing equipment unnecessary except for phantoming purposes. In the Hartford, Bristol, and Stamford tandem offices the later arrangement has been the most economical due to the excess of outgoing over incoming trunks. The outgoing holding equipment for trunks to manual offices is a comparatively inexpensive 2-relay circuit.

Switchboards in dial exchange areas are equipped with dials operated on a dial key or listening key basis, whereas in manual areas the operator's dial is associated with the tandem dial trunk by the dial cord method.

The equipment provided at manual switchboards for outgoing trunks to tandem is identical with that which would be used on circuits to a local step-by-step office in the same exchange area. Where phantom operation is desirable, a standard phantom composite unit originally designed for installation in step-by-step offices is provided at the manual office and inserted between the usual out-dial trunk equipment and the cable facility. The trunks from Willimantic to Hartford and from East Hampton to Hartford are examples of this arrangement.

The tandem completing trunk equipments in the various manual offices have the common characteristic of providing switchhook supervision to the originating operator, but differ otherwise in accordance with the design and traffic requirements of the particular board. Manual offices in a multiunit exchange having some dial equipment normally are provided with call indicator equipment, and tandem calls are completed over these call indicator trunks. In other manual switchboards, jack ended and cord ended completing trunks have been installed for tandem use. The calls on jack ended trunks are completed by the use of local cords that are modified to provide through supervision on tandem calls. The cord ended trunks usually are answered by the operation of a listening key, but they may be connected to the operator automatically. All straightforward trunks provide an order tone to the originating operator when the completing operator is ready to receive the details of the call.

In magneto offices it is not practicable to provide a signal to indicate the answer by the called party; therefore, it is necessary for the magneto operator to monitor until the start of conversation, then operate a charge key associated with the incoming trunk to retire the supervisory lamp at the originating switchboard.

The power supply requirements at tandem centers do not differ from those of ordinary step-by-step dial local offices that use a battery, the voltage of which is held between the limits of 45 and 50. In manual offices the battery voltages ordinarily provided have proved satisfactory even for composite signaling circuits requiring a 48 volt battery of not more than 5 volts variation.

Summary

The dial tandem method of handling interexchange telephone traffic in Connecticut, introduced as an adjunct of the comprehensive dial conversion program, has been developed to take a major place in the handling of toll traffic. The use of the tandem method affords a definite improvement over the earlier methods in speed and accuracy of service to the subscriber, in simple and more uniform operating practices, and in reduction in operating effort. The facility of disposal of toll calls over this system by local operators without measurable interference with regular local traffic has contributed greatly to the success of the method of accepting all station-to-station toll calls at local boards. A more uniform transmission plan for the telephone plant is possible now, and a flexible relationship between traffic, trunk terminal and switchboard equipment, and interexchange wire plant has resulted in economies of operation.

The present experience with the dial tandem method indicates the desirability of extending this

method to the other exchanges of the state as soon as it can be done economically.

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Revised Sphere-Gap Spark-Over Voltages

The subcommittee of the A.I.E.E. committee on instruments and measurements that has been working for the past 2 years on a revision of the sphere-gap spark-over voltages which are published in A.I.E.E. Standard Number 4 has completed the revision of values for the sphere gap settings. These are published herewith to enable anyone so desiring to make use of these values pending completion of a revision of the text of A.I.E.E. Standard No. 4 at which time they will be included in the revised standard. It is intended that no further change will be made in the values in the meantime.

The text of the present A.I.E.E. Standard No. 4 may be used in connection with the 60 cycle settings. This standard, however, does not adequately provide for use of the settings with impulse voltages, instructions for which are now being prepared.

For some time it has been known that there were errors in the standard values and also that they did not provide adequately for settings for use with impulse voltages. While the work of revision was going on tentative values were submitted to the International Electrotechnical Commission through the U.S. national committee representative at the meeting last summer. Since the 60 cycle values were in agreement with the latest work of some of the other national committees, the I.E.C. promptly adopted and published values that are substantially the same in I.E.C. publication 52 entitled "Rules for the Measurement of Test Voltage at Power Frequencies in Dielectric Tests by Sphere Gaps."

60-Cycle Sphere-Gap Spark-Over Voltages (Kilovolts)

(At 25 Degrees Centigrade and 760 Millimeter Barometric Pressure; One Sphere Grounded)

Sphere Gap Spacing, Centimeters	Sphere Diameter—Centimeters 6.25	12.5
0.5	16.2	
1.0	31.0	31.7
1.5	44.5	44.9
2.0	57.0	58.0
2.5	68.8	70.8
3.0	78.8	83.5
3.5	86.6	95.0
4.0	93.6	106.0
4.5	99.8	117.0
5.0	105.5	127.0
5.5		135.3
6.0		143.5
6.25		147.5
7.0		157.7
8.0		170.5
9.0		182.0
10.0		
11.0		
12.0		
12.5		

60-Cycle Sphere-Gap Spark-Over Voltages (Kilovolts)

(At 25 Degrees Centigrade and 760 Millimeter Barometric Pressure; One Sphere Grounded)

Sphere Gap Spacing, Centimeters	Sphere Diameter—Centimeters 25	50	75
2.5	72		
5.0	136	136	136
7.5	192	197	200
10.0	241	260	261
12.5	278	317	324
15.0	309	367	380
17.5	338	411	433
20.0	362	451	484
22.5	379	486	528
25.0	393	519	573
30.0		573	653
35.0		615	721
40.0		651	777
45.0		681	827
50.0		707	870
55.0			910
60.0			945
65.0			977
70.0			1,003
75.0			1.025

60-Cycle Sphere-Gap Spark-Over Voltages (Kilovolts)

(At 25 Degrees Centigrade and 760 Millimeter Barometric Pressure; One Sphere Grounded)

Sphere Gap Spacing, Centimeters	Sphere Diameter—Centimeters 100	150	200
10	261	261	261
20	504	505	506
30	700	736	746
40	862	947	973
50	985	1,120	1,172
60	1,084	1,254	1,346
70	1,163	1,360	1,505
80	1,234	1,458	1,635
90	1,295	1,552	1,752
100	1,338	1,628	1,857
110		1,695	*1,944
120		1,760	2,027
130		1,815	2,103
140		1,865	2,169
150		1,900	2,231
160			2,293
170			2,343
180			2,395
190			2,436
200			2,475

* The values for the 200 centimeter sphere gap for spacings over 100 centimeters are extrapolated.

Frequency Tripling Transformers

The possibility of making use of transformer harmonic phenomena for frequency multiplication has long been recognized, but practical applications have been few. Within recent years, however, several frequency tripling transformers have been built for supplying 180 cycle energy to large electric horns and similar devices from 60 cycle sources. The inherently poor regulation of the output voltage and low power factor of the input circuit can be compensated in part by the use of series capacitance in the output circuit; at the same time the maximum output is increased considerably. Two suggested practical applications of these devices are for supplying 180 cycle energy to induction furnaces and to high-speed motor-driven tools.

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IN ANY a-c electrical apparatus in which the iron of a magnetic circuit is operated at a maximum flux density above the bend in the saturation curve, there is a tendency for harmonic frequencies of current or voltage, or both, to be produced. Transformers, in particular, having a magnetic circuit consisting entirely of iron and operating at flux densities ranging normally from 70,000 to 90,000 maxwells per square inch, may produce harmonics of appreciable magnitude. Because of their tendency to produce telephone interference, excessive dielectric stresses, and other troublesome conditions, the harmonics have long been considered detrimental, and precautionary measures against their effects have been necessary in design and operation.

The theoretical possibility of making use of transformer harmonic phenomena for frequency multiplication was recognized long ago, and within recent years a number of frequency tripling transformers have been manufactured and put into service, transforming 3-phase 60-cycle energy to single-phase 180-cycle energy. So far as is known to the writer, this represents the first practical application of static transformers for frequency changing.

A summary of the theory underlying the operation of frequency tripling transformers is given in this paper, together with characteristic curves as obtained by tests on units of several designs. Some of the possibilities for future development and application also are discussed.

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1. For all numbered references, see list at end of paper.

General Theory

The frequency tripling transformer depends for its operation upon the nonlinear characteristics of the magnetization curve of iron. The permeability of transformer core steel, in common with all magnetic irons and steels, is not constant, but varies as a complex function of the flux density. Because of this, if a transformer be excited in such a way that its induced voltage is sinusoidal, the flux also will be sinusoidal, but the exciting current will contain odd harmonics. Conversely, if it be excited in such a way that its exciting current is sinusoidal, both the flux and induced voltage will contain odd harmonics. In general, the suppression of any harmonic in the exciting current will produce the corresponding harmonic in the flux and induced voltage.[1,2]

Figure 2*A* shows typical wave shapes of exciting current, flux density, and induced voltage for sinusoidal induced voltage, as determined from a typical magnetization curve as shown in figure 1. Figure 2*B* shows the corresponding shapes if only sinusoidal exciting current be permitted to flow. The relatively small effect of iron loss is neglected in these curves. It may be noticed that when harmonics are suppressed in the exciting current, corresponding harmonics appear in the voltage. If the third harmonic only be eliminated from the current, a pronounced third harmonic will appear in both the flux and the induced voltage.

Tripling Circuit. Figure 3 shows a bank of 3 2-winding transformers with their primary windings wye-connected and supplied from a 3-phase 60-cycle source. The secondary windings are delta-connected with one corner opened and brought out to form the output terminals. As the primary windings are wye-connected with neutral isolated, triple har-

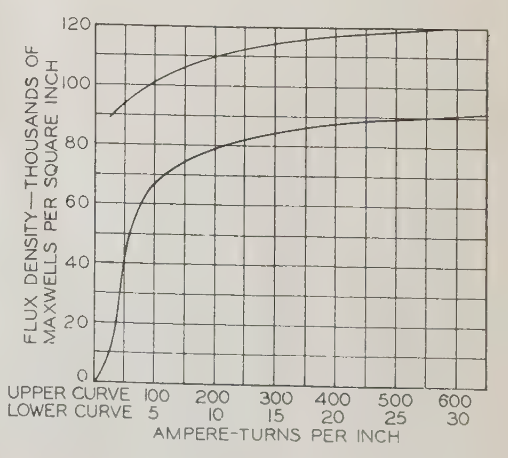


Fig. 1. Typical d-c magnetization curve for silicon steel

monics of current cannot flow in the primary circuit.[1] (The term "triple harmonics" is used to include all odd harmonics that are multiples of 3.) As they would be in phase in the 3 legs, no return path for them exists. The fundamental and nontriple harmonics of current, however, being in 120-degree or equivalent phase relation, can exist, the current of each phase finding its return path through the other 2 phases. No current can flow, of course, in the open-circuited delta.

As triple frequency currents cannot exist in either primary or secondary winding, triple frequency components must appear in the flux of each core and in the induced voltages. On the primary side, the voltages from line to neutral contain fundamental and triple harmonics. From line to line, however, the triple harmonics cancel, leaving only the fundamental. This satisfies the conditions imposed by the 60 cycle applied voltage. On the secondary side, as the fundamental frequency voltages of the 3 transformers are in 120 degree phase relation, their sum around the delta is zero and they do not appear at the output terminals. The triple harmonics of voltage, however, are in phase in the 3 transformers and their arithmetical sum around the delta appears at the terminals. Theoretically, the output voltage contains all triple frequencies of the 60 cycle applied voltage. Practically, though, the ninth, fifteenth, and higher harmonics are negligible compared with

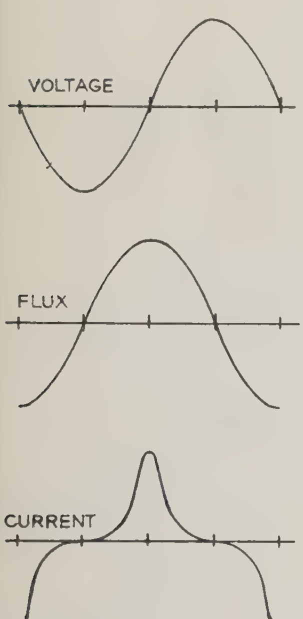


Fig. 2A. Typical wave shapes for sinusoidal voltage

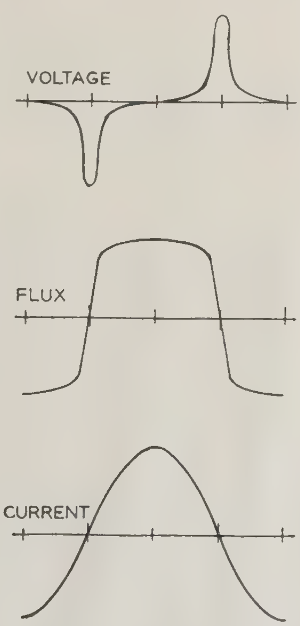


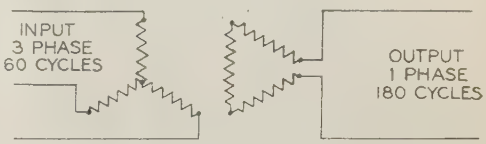
Fig. 2B. Typical wave shapes for sinusoidal current

the third. This circuit, therefore, is capable of transforming a 3 phase voltage into a single phase voltage with a frequency 3 times as great.

If the secondary terminals (figure 3) be short-circuited, the circuit becomes the equivalent of a wye-delta transformer bank operating at no load. The triple frequency currents flowing in the closed-delta secondary circuit, acting as part of the exciting current, suppress the triple harmonics of flux and induced voltage, leaving fundamental frequencies only. The wave shapes of total exciting current, flux, and induced voltage are then as shown by figure 2*A*.

If an impedance load be connected in the output circuit, triple frequency current will flow through the load. At no load or short circuit, with losses neglected, the fundamental frequency current in the

Fig. 3. Frequency tripling circuit



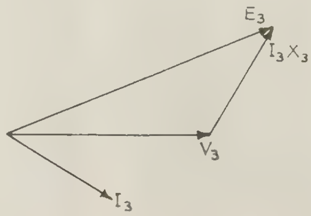


Fig. 4. Vector diagram for output circuit of figure 3

primary winding is in quadrature with the applied voltage and both the power input and output are zero. With a load connected, the secondary current changes the shape of the flux wave in such a way that the fundamental current in the primary winding shifts in phase and magnitude so that power is taken from the supply circuit. The fifth, seventh, eleventh and higher harmonics of current in the primary winding contribute nothing to the average power input as there are no corresponding harmonics in the applied voltage. As these harmonics cannot exist in the flux and induced voltages, they must appear as components of exciting current.

With a load connected across the output terminals, the loads drawn from the 3 input phases are balanced. Although with losses neglected the input and output average powers are equal, in accordance with the law of conservation of energy, the instantaneous values in general are unequal. The power input is continuous, while the output, being of single-phase form, is pulsating. Thus, this transformer bank, in changing frequency from 60 cycles to 180 cycles, behaves in much the same way as a rotating machine, storing power during part of the cycle, and delivering it to the output circuit during the remainder of the cycle. In a rotating machine, the kinetic energy of the rotor acts as a reservoir of power to equalize the instantaneous differences between input and output; but in a transformer bank, this function is performed by the energy storage capacity of the magnetic fields. This performance, related as it is to magnetic saturation phenomena of iron, is somewhat involved in nature, but methods of analysis have been developed that will predict to a fair degree of accuracy the behavior of transformers operating in this manner.

It should be noted that the foregoing analysis applies in general to the transformer connection of figure 3, whether it is composed of 3 single-phase

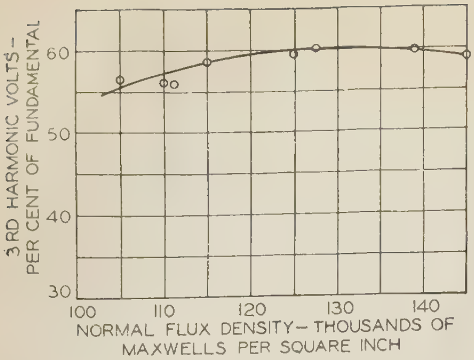


Fig. 5. Open-circuit third-harmonic voltage as a function of flux density in tripling transformer core

units or a single 3-phase unit. However, in a 3-phase core-type transformer having a 3 legged core, the third harmonic fluxes, being in phase in the 3 legs, must find a return path through the clamps, tank, and air. As the high reluctance of this path largely suppresses the third harmonic fluxes, this type of transformer is not suitable for efficient triple frequency transformation. This discussion, therefore, should be understood as applying to a bank of 3 single-phase transformers or to a 3-phase shell-type transformer.

Design Methods

F. F. Brailsford[3] has developed equations and methods for calculating the secondary, or output, characteristics of frequency tripling transformers. A summary of his methods and suggestions for calculating input currents, power factor, and efficiency, are given in the following paragraphs.

Secondary Vector Diagram. Consider a bank of 3 transformers connected as shown in figure 3. Figure 4 represents the vector diagram of third harmonic quantities in the secondary circuit, where E_3 is the open-circuit third-harmonic voltage across the output terminals, or the sum of the third-harmonic components of induced voltages in the 3 cores, and I_3 represents the load current.

As no 180 cycle current can flow in the primary windings to balance this load current, it produces a flux in the core, inducing a corresponding voltage which leads the current by 90 degrees. This voltage adds vectorially to E_3, giving the terminal voltage V_3. As may be seen on the vector diagram, the voltage induced by the load current behaves like the leakage reactance drop of a normal transformer. Therefore, it has been represented as I_3X_3, where X_3 is the equivalent third-harmonic reactance of the secondary circuit.

Strictly speaking, since the flux producing the voltage I_3X_3 exists practically entirely in iron, X_3 is not constant but varies as a function of the varying permeability of iron. However, this flux is superposed upon a much larger 60 cycle flux, the maximum density of which is well above the bend in the magnetization curve. As a result, the iron is saturated during a considerable portion of the cycle, and X_3 may be considered constant at least for first approximations.

Determination of X_3 and E_3. The reactance X_3 may be obtained easily from tests. With rated 60 cycle voltage applied to the input side of the tripler, the open circuit secondary voltage E_3 and the short circuit secondary current I_s are measured. The reactance is then simply:

$$X_3 = \frac{E_3}{I_s} \text{ ohms} \tag{1}$$

Brailsford gives a relation for approximating the value when tests are not available:

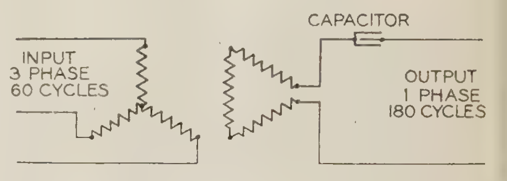
$$X_3 = \frac{71}{10^8} \times \frac{fAT^2u}{L} \tag{2}$$

where

f = fundamental frequency in cycles per second
A = cross-sectional area of iron in each core in square inches
T = number of secondary turns on one core
u = permeability of iron at maximum flux density
L = mean length of magnetic circuit of each core in inches

Perhaps a more accurate, but also more laborious, method of determining X_3 is by harmonic analysis

Fig. 6. Compensated frequency tripling circuit



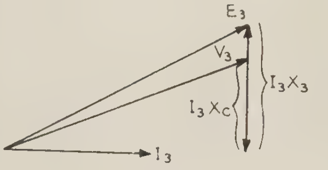


Fig. 7. Vector diagram for output circuit of figure 6

of the voltage and current waves as determined from the magnetization curve of the cores being used. With the secondary winding short-circuited, the only appreciable flux in the cores is the 60 cycle fundamental, determined by the applied voltages. From the magnetization curve, the corresponding current wave is determined point by point and plotted. By means of a harmonic analysis the third harmonic of this wave is determined; this then is I_s. Harmonics above the seventh are usually small in magnitude and are neglected; their inclusion would complicate further analysis to an unsurmountable degree.

The voltage E_3 is determined by the same method, but a process of successive approximation must be used. With the third-harmonic current suppressed by the open circuited delta, third harmonics appear in the flux and induced voltage. The phase positions of these harmonics are known. Various magnitudes of third-harmonic flux are assumed until one is found that, when combined with its fundamental and carried through the magnetization curve as before, will give a current with zero third harmonic. The voltage corresponding to this third-harmonic flux is E_3 and the current, referred to the primary side, is the wattless component of no-load input current. Usually 2 or 3 trials will give the solution to a reasonable degree of accuracy.

Then I_s and E_3 being known, X_3 is obtained from equation 1. The 180 cycle vector diagram now may be drawn, and the output voltage and regulation may be predicted for any type of load.

Determination of Primary Currents. The primary currents for a given secondary load must be determined by a harmonic analysis similar to the one described previously for determining the open circuit voltage E_3. From the 180 cycle vector diagram, voltage I_3X_3 is determined. The corresponding 180 cycle flux is added in its proper phase position to the open circuit flux curve, which already has been determined. The current curve corresponding to the resultant flux then is plotted point by point as before, and is subjected to a harmonic analysis. The third harmonic of current, referred to the secondary side, should check with the originally assumed load current. The fundamental, and the fifth and seventh harmonics, referred to the primary side, give the input currents, losses neglected. The average power input, as determined from the input

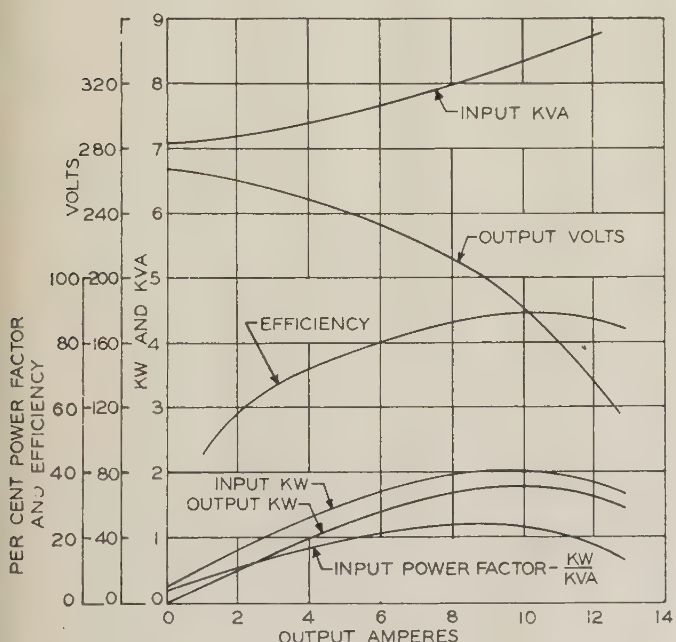


Fig. 8. Tested characteristics of 1¼ kw frequency tripler with unity power factor load

current and applied voltage, should check with the assumed average power output.

These 2 checks will not be exact because of the errors introduced by harmonics above the seventh being disregarded and also because the reactance X_3 does not remain entirely constant. If on the first attempt the values do not check within allowable limits of accuracy, the solution should be repeated with slightly different values of X_3 until satisfactory checks are obtained.

Determination of Losses. As the iron loss curves ordinarily used in transformer design are based upon sinusoidal fluxes, they cannot be used directly for calculating the core losses of the frequency tripler. However, methods for calculating iron losses under nonsinusoidal conditions are well known[4,5] and are not repeated here. The core loss is calculated, and the corresponding loss current is added in its proper phase relation to the input current determined by harmonic analysis. The resultant is the total input current, determined in magnitude, wave shape, and phase position.

The copper losses are calculated from winding currents and effective resistance according to usual methods.

Efficiency. The efficiency is found from the usual relation:

$$\text{Per cent efficiency} = \frac{W_3}{W_3 + W_L} \times 100 \qquad (3)$$

where W_3 and W_L represent output and total losses, respectively, in watts.

Power Factor. Because of the high secondary reactance and low excitation reactance of the frequency tripler, the lagging reactive kilovolt-amperes on the input side are appreciably greater than those of the load. For convenience this situation is analyzed by the determination of input power factor for given conditions of load.

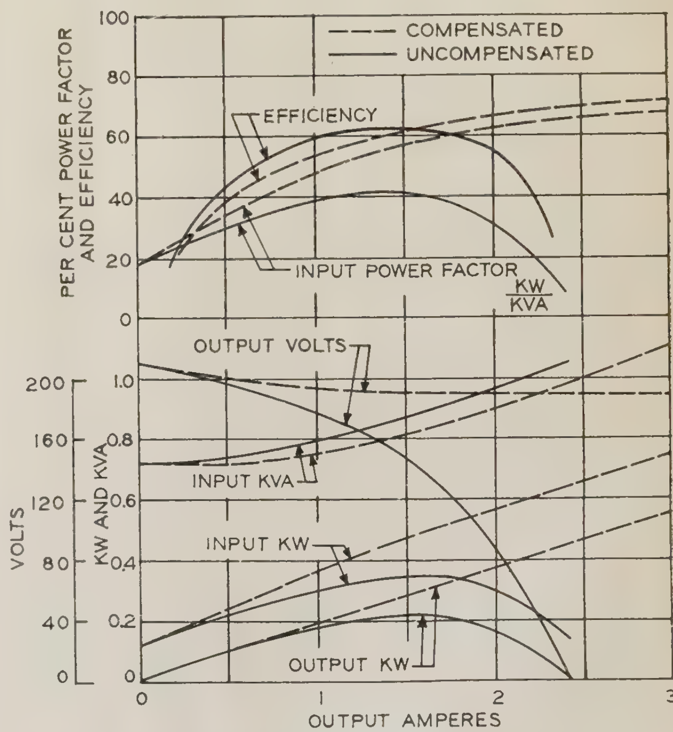


Fig. 9. Tested characteristics of 0.15 kw frequency tripler with unity power factor load

Power factor usually is defined as watts divided by volt-amperes. In a circuit involving only single frequency sinusoidal quantities, the power factor may be defined also as the cosine of the angle of phase displacement between the vectors of voltage and current. In the case of nonsinusoidal quantities, however, the latter definition no longer has the

same significance because each harmonic of current has an angular displacement from the corresponding harmonic of voltage differing, in general, from that of the fundamental or any other harmonic.

The primary current of the frequency tripler contains pronounced harmonics, but the applied voltage usually is practically sinusoidal. As only fundamental frequency voltages exist between the input lines, a power factor meter, which gives an indication based upon phase angles, connected in these lines will indicate the power factor corresponding only to the fundamental frequency, disregarding entirely the higher current harmonics. However, measurements by the wattmeter-voltmeter-ammeter method will take into account all harmonics, and will give a value based upon the first and most general definition.

The power factor of the frequency tripler may be determined from the calculated values of input currents according to either of these conceptions. However, a clear statement as to which kind of power factor is meant should be given with each set of values.

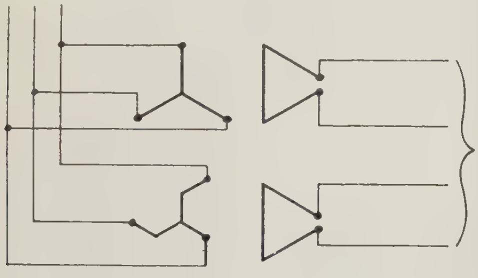


Fig. 10. Connections of frequency tripler for 2 phase output

Flux Density. Suppose that the iron cores are operated at a low maximum flux density, for example, 40,000 maxwells per square inch. As the magnetization curve is practically a straight line up to this density, the third harmonics generated would be negligible. Suppose, however, that the cores are operated at an extremely high density, for example, 200,000 maxwells per square inch. For this condition the portion of the magnetization curve above approximately 120,000 maxwells per square inch is straight and will contribute nothing to the generation of harmonics. At either of these extremes, production of third harmonics would be inefficient. The shape of the magnetization curve, figure 1, is such that a maximum flux density of 120,000 to 140,000 maxwells per square inch will make the most efficient use of the curved portion. Tests on specially built transformers have substantiated this conclusion. With increasing density, the third-harmonic voltage, expressed as a per cent of the 60 cycle applied voltage, increases to a maximum of about 60 per cent between 120,000 and 140,000 maxwells per square inch and then decreases. Figure 5 shows tested values obtained from transformers of several different designs over a flux density range of 105,000 to 140,000 maxwells per square inch.

From the standpoint of improved regulation and economy of material, higher flux densities theoretically might be desirable. However, the resulting higher core losses and lower input power factors would offset the advantages obtained. As will be shown, though, the regulation and material economy may be improved in another way—by the use of capacitors in series with the output circuit.

Compensation With Capacitors

The flux producing the voltage drop I_3X_3 exists almost entirely in a low reluctance iron path, but the leakage flux of a normal single frequency transformer is principally in air. Therefore, the reactance X_3 of the frequency tripler will be found to be several times greater than the leakage reactance of a normal transformer bank of equivalent size. This results in relatively poor voltage regulation, especially for inductive loads, and also in low maximum power output. The latter is, in a sense, a measure of the material economy, or apparatus utilization factor.

From the vector diagram, figure 4, the following expressions may be written:

$$V_3 = \sqrt{E_3^2 - I_3^2X_3(X_3 + 2X)} \tag{4}$$

$$W = \sqrt{E_3^2 - I_3^2(X_3 + X)^2} \times I_3 \tag{5}$$

in which X is the reactance of the load and W is the watts output, the other quantities being as defined previously.

If dW/dI_3 from equation 5 be equated to zero, the following expression is obtained for maximum watts output:

$$W_{max} = \frac{E_3^2}{2(X_3 + X)} \tag{6}$$

From these relations it is evident that the voltage regulation and the maximum power output are dependent upon the reactances of the transformers and of the load. Now if a capacitor be connected in series with the output circuit, as shown in figure 6, the equation for maximum output becomes:

$$W_{max} = \frac{E_3^2}{2(X_3 + X - 1/\omega C)} \tag{7}$$

It may be seen then that by proper selection of the value of $1/\omega C$, the maximum output can be raised to any desired limit. Theoretically, when $1/\omega C$ is equal to $X_3 + X$, the maximum power output becomes infinite; practically, it is limited by the losses in the circuit. The capacitive compensation, in addition, improves the regulation of the circuit, as may be seen from the vector diagram, figure 7, in which the capacitance drop I_3X_C has been added.

Test Results

The principles reviewed in this paper have been used in the design and manufacture within the last 5 years of a number of static frequency triplers now in successful operation. The units are rated 440 volts, 3 phase, 60 cycles input to 250 volts, single phase, 180 cycles, $1^1/_4$ kw, unity power factor output, and are used to operate large electric horns for fire

alarms and marine fog warnings, and in similar applications. In these designs only partial compensation was necessary, as strict limits of voltage regulation and apparatus utilization were not required. The capacitors used were connected in parallel with the load and neutralized only the reactance of the horn, leaving the transformer reactance uncompensated.

Tested operating characteristics of this frequency tripler supplying unity power factor load are shown by figure 8 and table I, column 1. These tests were made without capacitive compensation in the circuit. The curves show that the tripler will deliver its rated unity power factor output, 5 amperes, with approximately 11 per cent voltage regulation. The apparatus utilization, however, as expressed in watts output per pound of active iron, is somewhat low.

The input power factor of this tripler at full load is only 20 per cent. In other words, at 77 per cent efficiency, the input in volt-amperes is 6.5 times the output in watts. For this particular application, the low power factor is not considered serious as installations are made singly and used only at infrequent intervals. However, some means of improving the power factor probably would be necessary if any considerable capacity in frequency triplers should be installed in one location, operating more or less continuously.

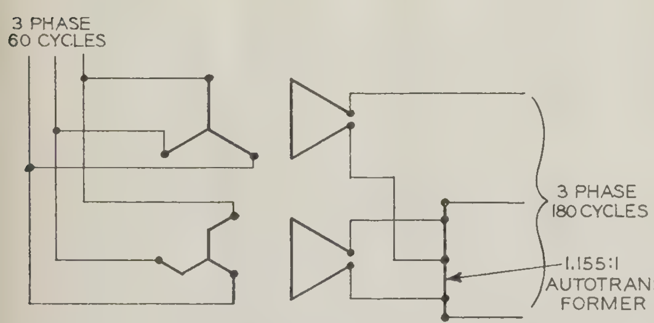


Fig. 11. Connections of frequency tripler for 3 phase output

Calculations indicate that a higher power factor could be obtained by the use of lower flux densities, but at the expense of output capacity. The most promising procedure, then, seems to be the use of lower densities for power factor improvement, together with the addition of capacitive compensation for maintaining output capacity.

Tests were made on a tripler designed for operation at a flux density 14 per cent below that of the previous design and having a unity power factor output rating of 150 watts, 190 volts, uncompensated. The results are shown by the solid line curves of figure 9 and by column 2 of table I. A comparison with column 1 shows that, because of the lower density, the output in watts per pound is only half that of the previous design. The input power factor, however, was raised from 20 to 36 per cent.

The tested reactance X_3 of this tripler is 89.4 ohms. For complete compensation, 9.9 microfarads of 180 cycle capacitors are required. Actually, a capacitor of 9 microfarads was added in series with the secondary. The results of tests with the capacitor in the circuit are shown by the broken line curves of figure 9 and column 3 of table I. Measurements were made for loads up to 3 amperes, almost 400 per cent of the uncompensated full load rating, and over this entire range the output watts followed practically a straight line and the output volts dropped only 12 per cent. On the basis of tested characteristics, the compensated tripler was given a normal output rating of 550 watts, 3.33 times the rating of the same tripler uncompensated. Its output in watts per pound of material is 4 times that of the uncompensated unit and twice that of the $1^1/_4$ kw uncompensated tripler. The greatest improvement, however, is in the input power factor. Reducing the flux density 14 per cent and adding capacitive compensation increased the power factor from 20 to almost 70 per cent and doubled the available output from a given amount of iron, with approximately the same voltage regulation.

The output side of the compensated tripler is essentially a circuit of resistance, inductance, and capacitance operating at or near series resonance. Therefore, under short circuit or heavy overload conditions, severe overvoltages may appear across the transformer windings and across the capacitors. Because of this, the transformer insulation should have a high factor of safety and the capacitors should be rated conservatively. For positive protection, some device should be used that either will open the secondary circuit or short circuit the capacitor at a definite value of overcurrent. For a small capacity tripler, a film cutout connected across the capacitor probably would be satisfactory. The rise in capacitor voltage would puncture the film, thus short circuiting the capacitor. The high reactance of the tripler then would limit the current to a safe value.

Table I—Characteristics of Compensated and Uncompensated Frequency Triplers—60 to 180 Cycles

		1	2	3*
Rated output (single phase)	watts	1,200	150	550
	amperes	5.0	0.79	2.9
	volts	240	190	190
Rated input (3 phase)—volts		440	480	480
Relative flux density		100	86	86
Capacitive compensation—microfarads		None	None	9
Maximum output—watts		1,840	220	Not measured
Relative maximum watts per pound of active iron		100	48.5	
Relative full load output—watts per pound active iron		100	51	186
Voltage regulation at full load—per cent		11	14	12
Input power factor†	no load	0.04	0.18	0.18
	full load	0.20	0.36	0.68
Efficiency at full load—per cent		77	54	74

* Column 3 shows same tripler as column 2 with capacitance added.
† Power factor is expressed as watts divided by volt-amperes.

Polyphase Output

In the foregoing discussion, the frequency tripler has been described as a bank of 3 single phase transformers. In practice, however, the 3 cores are

assembled in one case and only the input and output leads are brought out, all connections between coils being made internally. Essentially, therefore, the frequency tripler is a single piece of apparatus, delivering single phase power to the load. Of course, polyphase outputs can be obtained by proper combinations of single phase triplers. Figures 10 and 11 show connections for 2 and 3 phase outputs, respectively, from a 3 phase source.

Practical Applications

One disadvantage of tripling transformers that should be taken into consideration for any proposed application is the nature of the input current. It is not sinusoidal, but contains pronounced fifth and seventh harmonics. The importance of this characteristic should be evaluated in any particular installation. It will depend upon the location and the installed capacity of triplers.

Tests and experience so far have been limited to units of small size. However, it is believed that the methods used in the design of these units may be extended successfully to the design and construction of units having outputs of several hundred kilowatts, with characteristics approaching those of ordinary single frequency transformers. With such a range of sizes available, useful applications could be found in many fields.

The use of frequency tripling transformers for operating fire or fog warning signals already has been mentioned. Because of the remote locations in which many of these installations must be placed, transformer equipment is admirably suited to this service. In addition, the tripling transformer seems particularly suitable for supplying induction furnaces and other induction heating apparatus, as such apparatus can be operated more efficiently at higher frequencies. The triplers should be useful also for operating high-speed motor-driven tools. Motors operating at 180 cycles can be designed for a synchronous speed of 10,800 revolutions per minute, and such motors have been applied to portable drills, drill presses, and other motor driven tools and to machines for woodworking, shoe manufacturing, and similar processes.

Motor generator sets and induction frequency changers are the most commonly used devices for obtaining 180 cycle power from 60 cycle sources. For applications in which the relative reliability and freedom from maintenance of static devices are important factors, however, frequency tripling transformers may prove more satisfactory, especially for installation outdoors or in inaccessible locations.

References

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A Cold-Cathode Arc-Discharge Tube

A grid-controlled arc-discharge tube which requires neither power nor time for heating the cathode, but in which a discharge of several hundred amperes is controlled by an extremely small amount of power in the grid circuit, is described in this paper. The tube has characteristics especially useful in circuits requiring large peak current but low average current, some examples of which are given here, and is applicable particularly as a light source in stroboscopes.

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A NEW TYPE of grid-controlled gas-filled tube capable of passing peak currents of several hundred amperes has been developed which obtains the necessary electron emission from a cold cathode designed so that a cathode spot with low voltage drop is formed on a metallic surface by the concentration of a glow discharge. The active life of the cathode in the circuit applications which have been tried is more than 1,000 hours, and appears to be a function of the average current through the tube. The tube is ideal for applications which require occasional operation, for it has the ability to operate immediately without continuous consumption of cathode heating power, or without a time delay to heat the cathode. Although the tube was developed primarily for a stroboscopic light source, it has been successfully applied to other problems.

Cathode Development

One of the major problems in the design of gas filled tubes for large currents is the provision of a proper cathode. Development has progressed in 2 general directions: first, the heated cathode with its many heat-shielded emitting surfaces; and second, the mercury pool cathode with a cathode spot.

The heated cathode[1] requires power to keep it hot, and its life is a function of time as well as a function

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1. For all numbered references see list at end of paper.

of current. Considerable time is required after the cathode power has been turned on before the cathode reaches a temperature which will allow it to carry full load current. This time delay varies from 5 seconds to $^1/_2$ hour and is determined by the heating efficiency of the cathode, the most efficient cathodes ordinarily having the longest heating time. Hot cathodes are fairly well developed at present and are used in many gas filled tubes with success. Such cathodes must be heated continuously if the tubes are to be ready for immediate use.

The pool-type mercury-arc rectifier offers an example of the cathode spot method of obtaining electron emission from a metallic surface. The electron source appears as a brilliant spot of light on the surface of the cathode, and is in continuous motion unless stabilized by some such device as a metallic point protruding up through the mercury surface. Several amperes are required to maintain the spot, and some mercury arc rectifier tubes have auxiliary anodes to draw enough current to prevent the cathode spot from extinguishing. Several methods of starting a cathode spot are used, most of them requiring considerable power. These are:

1. The formation of a spark by interrupting a circuit at the surface of the mercury.[2] This is accomplished by a metallic plunger in the large rectifiers, and by rocking the tube in the small glass-tube type of rectifier.

2. The use of a high voltage suddenly applied to an electrode placed outside the glass near the boundary of the mercury cathode. This method is used for starting mercury lamps and has been very successfully applied to controlling mercury arc stroboscopic light sources,[3] in which case the starting voltage is accurately controlled by means of gas-filled grid-controlled thermionic tubes.

3. The use of the igniter type[4] of resistance starter in which a surge of current passes through a high resistivity rod projecting into the pool.

Tubes using cathode spots on metals other than mercury have not been considered practical, because the metallic cathode material is rapidly evaporated or sputtered away. The same phenomenon occurs in mercury cathodes, yet they are practical because the mercury may be returned to the cathode easily. The tube described in this paper obtains its emission from a cathode spot on metal with a caesium coating, but the design of the tube is such that for certain circuit applications the life of the cathode is long enough to make the tube of practical value.

Still another type of cathode is that used in glow discharge tubes.[5,6,7] In these cathodes the electron emission is obtained from a large area of metal by means of bombardment by positive ions. The voltage drop in such a tube is limited by the cathode fall of potential, which ranges from a minimum of about 50 volts to several hundred volts. The current carrying capacity of this type of tube also is limited by cathode heating and destruction of the cathode surface by bombardment with positive ions.

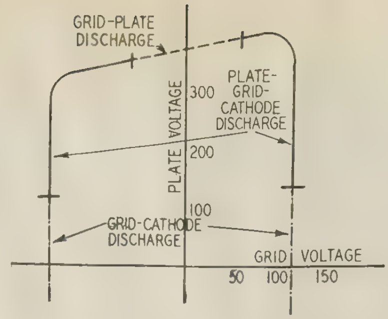


Fig. 2. Electrical breakdown characteristics of grid-controlled cold-cathode arc-discharge tube

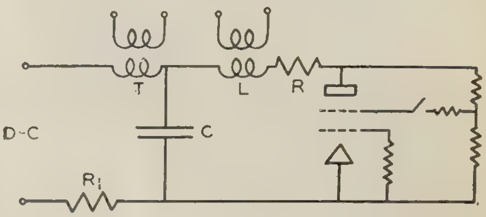


Fig. 3. Typical circuit for tube

Characteristics of the New Cold-Cathode Arc-Discharge Tube

The new type of tube described in this paper is especially suitable for application as a stroboscopic light source. Figure 1 shows a cross-sectional diagram and a photograph of the tube designed for use in a stroboscopic tachometer.

The cathode consists of a caesium compound which breaks down under the action of the cathode spot and liberates free caesium. Caesium was chosen because of the ease with which it permits spot formation, and to facilitate further the formation of the cathode spot the surface of the cathode is made rough and irregular. Surrounding the cathode is a ceramic insulator which concentrates the discharge on the active portion of the cathode, and also serves as a support for the inner grid.

Directly above the cathode is a wire mesh screen which may be referred to as the inner grid. This inner grid becomes coated with caesium during the operation of the tube, which lowers the breakdown voltage to it when it is negative with respect to the other electrodes. Above the inner grid is the grid proper, which is made of graphite. This material is used for the grid because the caesium that con-

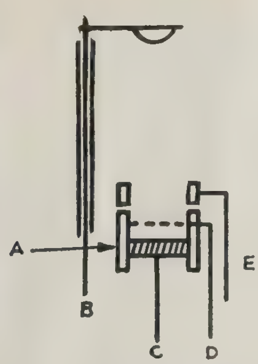


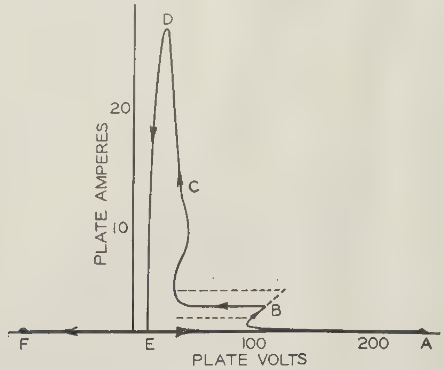
Fig. 1. Grid-controlled cold-cathode arc-discharge tube, and diagram showing arrangement of elements

A—Ceramic insulator
B—Plate
C—Cathode
D—Inner grid
E—Grid

denses on it does not lower the breakdown voltage to it, thus permitting a higher anode voltage.

About an inch above the grid is the anode, the anode support wire being insulated by means of a glass sleeve to prevent the discharge from taking the shorter path to the anode support. During the operation of the tube there is a bright column of light about $^1/_4$ inch in diameter extending from the anode to the cathode.

Fig. 4. Transient volt-ampere characteristics of tube



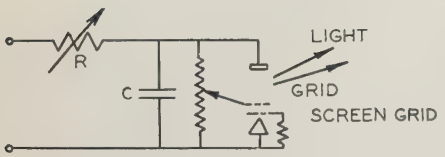


Fig. 5. Circuit for use of tube in stroboscope

R—2,000–50,000 ohms

C—4 microfarads

Any one of the noble gases—argon, neon, or helium—may be used in the tube, the usual pressure being from 1 to 2 centimeters of mercury. Neon is preferred when the tube is used as a stroboscopic light source because of its greater light output, but for control purposes a tube filled with argon is equally useful.

The discharge in the tube starts as a glow and immediately transfers to an arc with a cathode spot if the circuit to which the tube is connected is capable of supplying sufficient power. In normal use the tube is not operated as a glow discharge device but as an arc discharge tube, for it has been found that a cathode spot will form readily and consistently. Special circuits are required in order that the initial current shall have a value sufficiently high to cause the transfer from glow to arc, but the average current must be limited to a value that will not cause overheating.

Typical characteristics of a tube as used in the stroboscopic tachometer are as follows:

Breakdown voltage, inner grid to cathode	100 to 120 volts
Breakdown voltage, grid to inner grid	100 to 120 volts
Breakdown voltage, plate to grid	300 to 400 volts
Peak current	200 to 300 amperes
Average current	50 milliamperes
Life (operating 60 times per second under the above conditions)	500 to 1,000 hours

When the breakdown voltage between any 2 elements of the tube is exceeded, a glow discharge starts. This is normally brought about by causing the voltage between the grid and inner grid to exceed the breakdown point, the inner grid being negative. Either grid may be used as the control grid, depending on the polarity and magnitude of the control voltage.

Figure 2 is a graph of the breakdown characteristics of the tube, showing that the breakdown voltage of the grid to the inner grid is constant, with the inner grid at cathode potential, if the plate voltage is less than about 400 volts. For plate voltages larger than this, the discharge will start between the plate and the grid. The curve shows that the plate voltage, to cause breakdown, increases as the grid voltage increases, until the grid voltage reaches a value where breakdown occurs to the inner grid from the grid. In experimental determining these characteristics the inner grid was connected to the cathode through a 10,000 ohm resistance.

The breakdown characteristic is unsymmetrical about the grid voltage axis on the diagram shown in figure 2, since the breakdown voltage is a function of the condition of the surface of the particular element that is being used as the cathode. That is, the initial breakdown with the inner grid as cathode occurs at a lower voltage than with the inner grid as anode, because of the caesium on the inner grid.

Operation of the Cold-Cathode Arc-Discharge Tube

Figure 3 shows a typical circuit for the tube of figure 1. When the tube becomes conducting, the energy in the capacitor is dissipated in the impedance represented by L and R and the tube. If the impedance is too large, the current will not rise to a value necessary to form a cathode spot, and the discharge in the tube will remain a glow, with the resulting high tube drop. The maximum value that the impedance may have will depend on the value of the capacitance C and the supply voltage V. An impedance R_1 limits the flow of charging current to the capacitor, preventing a too rapid increase of voltage across the capacitor after it has been discharged. This impedance may be a combination of resistance and inductance, although resistance alone is satisfactory. In one of the applications given later, the impedance R_1 is the coil of a message register. A transformer T may be used to produce a pulse of voltage when the capacitor charges.

An important characteristic of the type of circuit shown in figure 3 is that the arc will extinguish itself even if the supply is direct current. This comes about in the following manner. The impedance of the tube and capacitor circuit is low and allows a

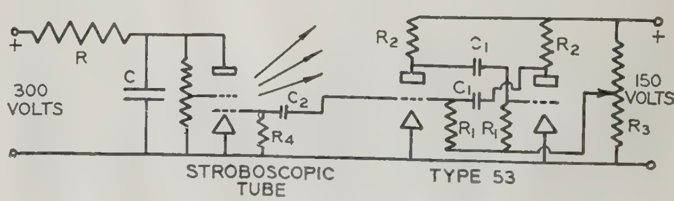


Fig. 6. Circuit of oscillator controlled stroboscope

R—1,500 ohms
R_1, R_4—1 megohm
R_2, R_3—100,000 ohms

C—4 microfarads
C_1—0.2 microfarad
C_2—0.001 microfarad

large momentary current to flow, which results in an arc of low drop. However, when the capacitor has discharged to a voltage approximately equal to the arc drop, the tube current can be maintained only by the flow through the charging resistor R_1. The values of this resistor and the voltage of the d-c supply must be such that this residual current is too small to maintain the cathode spot. When this is the case, the tube drop must rise to that necessary to maintain a glow discharge, which is some 10 times that necessary to maintain the arc. However, by the time the capacitor (and tube) voltage has risen to this value the tube has had time to deionize, and hence has returned to its normal nonconducting state, and will remain so until the next grid impulse. The tendency to extinguish may be assisted further by a discharge circuit of an oscillatory nature, as in figure 3. Capacitors are normally used in circuits employing the tube, since they offer a means of securing the momentary large currents necessary to start the cathode spot, and under proper conditions they offer a means of extinguishing the arc without breaking the plate circuit of the tube.

The volt-ampere characteristic of a tube in actual use, as observed experimentally by a cathode-ray tube, is given in figure 4. It was necessary to use a cathode-ray tube with an accelerating voltage of 5,000 volts in order to get sufficient intensity to be able to see the transitory part of the curve (A B C in figure 4) because this part of the volt-ampere characteristic was passed over very rapidly. Furthermore, transfer from glow to arc did not occur at a definite value of current each time, as is indicated by the dotted lines showing the extent of the variation. At the point C on the curve the drop in the tube was about 35 volts, and at E it was about 15 volts. This drop varies with time as well as with current, after initiating the discharge, as is clearly shown by the volt-ampere characteristic, which is different for increasing than for decreasing current. At the point E the arc extinguishes, and the voltage across the tube becomes negative (F) if the resistance R shown in figure 3 is less than that needed to damp the circuit critically. The tube does not form a glow or an arc with the reversed polarity if the voltages are not too high. As the capacitor C charges through the impedance R_1, the voltage progresses from F to E and finally to A in readiness for the next flash. The constants of the circuit in figure 3 for giving the characteristics shown in figure 4 were:

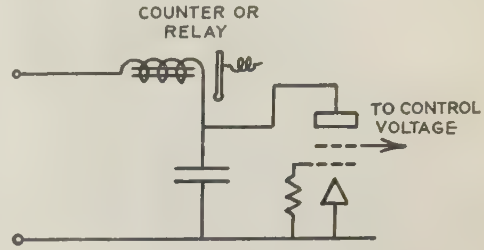


Fig. 8. One form of counter or relay circuit using cold cathode tube

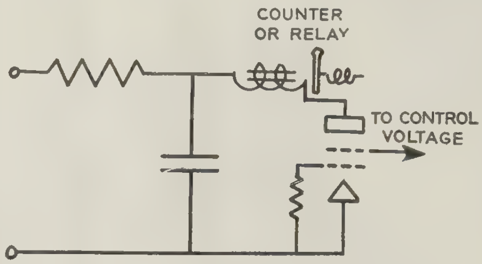


Fig. 9. Another form of relay circuit using cold cathode tube

V_p = 300 volts
R_1 = 3,500 ohms
C = 3 microfarads
R = less than 10 ohms
L = 0.1 millihenries
f = 120 cycles per second, switching frequency

The peak current is a function of the capacitance and the inductance. In stroboscopic light applications of the tube, the inductance becomes only that in the leads and in the capacitor. The peak current then becomes very high, approaching several hundred amperes.

If the resistance R in the discharge circuit is increased, the inverse voltage shown at F (figure 4) is reduced, and if the resistance is made large enough, the tube will "hold over" into a continuous glow discharge. No general rule has been formulated for the maximum allowable resistance, for in all applications that have been tried, the resistance is purposely quite small in value. The maximum allowable resistance is considerably greater than the critical damping resistance of the LC circuit.

Applications

The successful use of the tube that has been described depends on the proper recognition of its special characteristics. It is particularly well adapted to circuits requiring large momentary currents but relatively small average currents. The large momentary current required to form the cathode spot is readily obtained from a capacitor discharge, and in all of the following applications a capacitor is used with the tube.

Fig. 7. A stroboscope using the cold-cathode arc-discharge tube

The tube was developed primarily as a stroboscopic light source, large cathode emission being necessary to permit the high peak currents which produce the bright flashes of light for stroboscopic illumination. The simplest stroboscopic circuit is of the relaxation oscillator type as shown in figure 5. The capacitor is charged from a source of direct current through the adjustable resistor *R*. When the voltage across the capacitor reaches a value where the breakdown voltage between the grids is

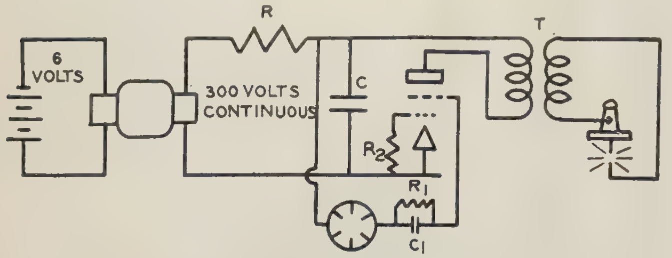


Fig. 10. Circuit arrangement for producing controlled sparks

R—1,500 ohms	*C*—0.15 microfarad
R—1 megohm	*C*—0.0005 microfarad

T—Spark coil

exceeded, the tube becomes conducting and the capacitor discharges through it, producing a bright flash of light. The discharge lasts only a few microseconds, and the current in the tube reaches a value of several hundred amperes. In this type of circuit there is sufficient inductance in the capacitor and leads to the tube to produce oscillations, and as has been explained above, because of this the voltage across the tube goes below the potential required for maintaining a continuous discharge. This allows the tube to deionize so that it will not remain conducting and form a steady glow discharge when the voltage across the capacitor rises, due to the charging current from the power source. The phenomenon described above is important in that it helps to extinguish the arc without the necessity of opening the plate circuit.

When the voltage across the capacitor again reaches the critical value, the capacitor discharges through the tube, and the sequence repeats at regular intervals, giving flashes of light at a constant frequency. The frequency can be changed by varying the resistance *R*, or the voltage of the power supply. To eliminate undesired changes in frequency with changing supply voltage, the circuit in figure 6 has been developed, in which the tube is driven by an oscillator of the multivibrator type.

The stroboscopic lamp circuit is similar to that in figure 5. However, the positive bias on the grid is adjusted so that the critical value of voltage between grids will not be exceeded even when the capacitor is fully charged. The driving oscillator is coupled to the inner grid of the tube through a small capacitor, and gives the inner grid a negative voltage pulse which starts the discharge.

The multivibrator control oscillator is of a conventional type except for the method of varying the frequency. The oscillator frequency is changed by varying the positive bias on the grids, as this method gives both a linear frequency scale and a wide frequency range (6 to 1). The multivibrator oscillator is remarkably stable and practically free from frequency changes resulting from varying supply voltage, and is well suited as a frequency control for a stroboscope.

A stroboscope now being manufactured, and shown in figure 7, uses a circuit similar to that just described. The instrument is intended primarily for use as a tachometer, and the frequency control dial is calibrated in revolutions per minute. It has 2 frequency scales ranging from 600 to 14,400 flashes per minute, and is calibrated with an accuracy of about 2 per cent of full scale reading. The instrument is useful for measuring directly the speed of rotation or vibration of objects, as well as serving as a stroboscope. The flashes may be controlled by means of an external contactor; or synchronized with the 60 cycle mains.

An excellent application of the arc discharge tube occurs in relay and counting circuits. The tube permits the passage of heavy currents, which makes it possible to construct a very quick acting relay or counter. There are 2 general types of circuits shown in figures 8 and 9. In figure 8 the relay or counter is operated by the charging current of the capacitor and it should be a fairly high impedance device; at least 500 ohms. In figure 9 the counter or relay is operated by the discharge current of the capacitor, and should possess low impedance. A circuit similar to figure 8 has been employed in a portable battery-operated cosmic-ray counter developed by Drs. E. M. Pritchard and R. D. Bennett at the Massachusetts Institute of Technology. Battery operation of this device became possible only when a high-current low-voltage cold-cathode tube such as that herein described was developed.

Gas engine ignition offers an application of the tube, as indicated in the circuit shown in figure 10. The tube does not require cathode heating power or a time delay for heating. Advantages of this circuit are:

1. Negligible wear of breaker points
2. Low battery drain at low speed
3. An equally powerful spark at all speeds; in particular, at low and high speeds
4. More accurate timing than with the usual breakers
5. Elimination of contacts of the cam type

The principal disadvantage is that a fairly high steady voltage (250 volts) is needed. Motor generators or vibrators such as those developed for automobile radios are satisfactory for this purpose.

The circuit for automobile ignition is also suitable for spark recording on paper. There are a number of high speed recorders that utilize a spark through paper as an indicator, and the circuit shown in figure 10 supplies a hot spark that can be accurately controlled with very little power.

A further application of the circuit of figure 10 is for the starting of mercury pool tubes. The high

(*Continued on page 809*)

Report of the Board of Directors

The board of directors of the American Institute of Electrical Engineers presents herewith to the membership its fifty-second annual report, for the fiscal year ending April 30, 1936. A general balance sheet showing the condition of the Institute's finances on April 30, 1936, together with other detailed financial statements, is included herein. This report contains a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in ELECTRICAL ENGINEERING.

Board of Directors' Meetings

During the year, the board of directors held 5 meetings, 4 in New York City, and 1 at Cornell University, Ithaca, N. Y. The executive committee meetings in December and March were held in place of regular meetings of the board. Information regarding many of the more important activities of the Institute which have been under consideration by the board of directors and the committees is published each month in the section of Electrical Engineering devoted to "News of Institute and Related Activities."

President's Visits

President Meyer attended the Pacific Coast and winter conventions and the Great Lakes District meeting. He also visited many Sections, and a considerable number of educational institutions in their vicinities. In several cases, he addressed general assemblies of students or assemblies of engineering students, while in certain other cases he spoke at meetings of the A.I.E.E. Student Branches. The places visited are listed below:

Seattle, Wash. (Pacific Coast convention); University of Washington, Seattle; Spokane, Wash.; Portland, Ore.; San Francisco, Calif.; University of California, Berkeley; Los Angeles, Calif.; California Institute of Technology, Pasadena; St. Louis, Mo.; Washington University, St. Louis, Mo.; Purdue University, Lafayette, Ind. (Great Lakes District meeting); Rhode Island State College, Kingston; Providence, R. I.; Brown University, Providence; Washington, D. C. (American Engineering Council); Pittsburgh, Pa.; Erie, Pa.; New York, N. Y. (winter convention and other meetings); Kansas City, Mo.; University of Kansas, Lawrence; Kansas State College, Manhattan; Oklahoma City, Okla.; University of Oklahoma, Norman; Dallas, Texas; University of Texas, Austin; San Antonio, Texas; A. & M. College of Texas, College Station; Houston, Texas; Rice Institute, Houston; New Orleans, La.; Tulane University, New Orleans, La.; Louisiana State University, Baton Rouge; Memphis, Tenn.; Louisville, Ky.; University of Louisville; Pratt Institute, Brooklyn, N. Y.; Newark Technical School, and Newark College of Engineering, Newark, N. J.; and Rutgers University, New Brunswick, N. J.

During May and June, President Meyer will visit the Cincinnati, Cleveland, Philadelphia, and Sharon Sections, and will attend the North Eastern District meeting, New Haven, Conn., and the summer convention, Pasadena, Calif.

National Conventions

Three national conventions were held during the year, and a brief report on each follows.

Summer Convention. The fifty-first summer convention was held at Cornell University, Ithaca, N. Y., June 24–28, 1935. Thirty-nine papers were presented during the 10 technical sessions, and in addition 2 special addresses were presented. Other parts of the convention were the annual business meeting of the Institute, conference of officers, delegates, and members, golf and tennis tournaments, president's reception and dance, banquet and ladies' events. The Lamme Medal for 1934 was presented to Henry E. Warren, of Ashland, Mass. The registration was 904.

Annual Meeting. The annual business meeting of the Institute was held on Monday morning June 24, as part of the opening session of the summer convention. The annual report of the board of directors for the fiscal year ending April 30, 1935, was presented in abstract, and the committee of tellers reported upon the election of officers for the administrative year beginning August 1, 1935. President-elect Meyer responded with a brief address. The committee of tellers also reported the adoption by the membership of the proposed amendments to the A.I.E.E. Constitution changing the dates of certain steps in the election procedure.

Pacific Coast Convention. The twenty-third Pacific Coast convention of the Institute was held in Seattle, Wash., August 27–30, 1935. The registration was 269, and the attendance at the technical sessions was excellent. The technical program included 16 papers at 5 sessions; also 3 special illustrated talks, and, in addition, 10 student papers at 2 regular sessions held for their presentation and discussion. Especially attractive entertainment events and trips were included in the program.

Winter Convention. The twenty-fourth winter convention, held in New York City, January 28–31, 1936, was opened by a brief general session including an address of welcome by C. R. Beardsley, chairman of the winter convention committee, an address by President Meyer, and a brief announcement regarding the technical sessions by W. R. Smith, chairman of the technical program committee. A. M. MacCutcheon announced the award of the Mascart Medal to Dr. A. E. Kennelly, past-president of the Institute. During the 14 sessions held on the first 3 days, 59 papers were presented. At an evening session, the Edison Medal was presented to Dr. L. B. Stillwell, past-president of the Institute, and Dr. Harlow Shapley, director of the Harvard College Observatory, gave a lecture on "Progress in Measurements of the Universe." Numerous inspection trips

aroused an unusual amount of interest. The registration was 1,231.

District Meeting

One District meeting was held during the year, and a brief report follows.

Great Lakes District Meeting. The fifth Great Lakes District meeting was held at Purdue University, Lafayette, Ind., October 24–25, 1935. The total registration was 457, including about 250 students. The program included 15 technical papers, 2 special addresses, 15 student papers, inspection trips, and entertainment events.

Sections

As measured by interest and enthusiasm, as well as by the statistics on meetings and attendance, the Sections had a year of outstanding success. Although no new Sections were formed during the year, the total number of meetings was the largest ever reported for a fiscal year, and practically all Sections carried on a normal amount of activity.

There was a marked increase in interest in technical groups, special technical meetings, and other features especially attractive to considerable numbers of members.

The Sections which have been holding meetings with neighboring Branches for the presentation of programs by students and those which have held annual meetings for competition among their members continued, with good results in nearly all cases.

Under authorization voted by the board of directors at its August meeting, the president appointed a committee to initiate and carry out a suitable national celebration of the fiftieth anniversary (March 20, 1936) of the establishment of the alternating current system in America. The committee decided to hold a dinner meeting in New York City on March 20 and to encourage Institute Sections to hold meetings on or near that date, with programs commemorating the event and bringing out facts regarding the importance of the alternating current developments in their vicinities. About 54 Sections held such meetings. More than 500 attended the dinner meeting in New York.

More detailed information on these activities may be found in the annual report on Section and Branch activities in the June issue of Electrical Engineering, pages 752–4.

Student Activities

A Branch was organized at the University of Maryland, College Park, in March 1936, under authorization granted by the executive committee of the Institute on March 9, bringing the total number to 118.

Many of the Branches were exceptionally active during the year, with only a comparatively small number carrying on little or no activity, and the total number of meetings reported was 1,045, which is the largest number for any fiscal year since that ending on April 30, 1932.

Some of the Branches have shown a renewed realization of the fact that the effectiveness of their activities and their value to the students are dependent upon the amount of student participation in the programs. Many Branches had considerable numbers of talks by students with good results, but this highly important part of Branch activity is still being neglected in many cases.

The terms of enrollment of 1,226 students expired on April 30, 1936, and about 50 per cent applied for admission as Associates.

Students have continued to take active parts in the programs of the Pacific Coast convention and the District meetings, and have shown keen appreciation of these opportunities to form contacts with practicing engineers.

Additional information on these activities appears in the annual report on Section and Branch activities in the June issue of Electrical Engineering, pages 752–4.

Section and Branch Statistics

Data on the Sections and Branches are given in table I.

Table I—Section and Branch Statistics

	For Fiscal Year Ending			
	April 30, 1930	April 30, 1932	April 30, 1934	April 30, 1936
Sections				
Number of Sections	56	60	61	61
Number of Section meetings held	480	497	472	540
Total attendance	84,615	105,325	73,271	85,501
Branches				
Number of Branches	106	109	113	118
Number of Branch meetings held	1,009	1,135	1,015	1,045
Total attendance	50,401	54,197	41,772	45,304

Technical Program Committee

The work of the technical program committee has continued uninterrupted throughout the past year, and has been carried on along the lines of procedure which have been developed out of the experience of previous committees, especially those of the past several years. Four meetings of the committee were held during the year. Under the present publication policy of the Institute the committee's 2 especial responsibilities are:

1. The reviewing of all papers to determine their suitability for publication in Electrical Engineering.

2. The selection of papers for presentation at national conventions and the arrangement of such papers into programs for technical sessions. In this connection consideration is given to the needs of District meetings and assistance rendered to those locally in charge of the programs for such meetings.

The committee deems of primary importance in connection with its review and approval of papers for publication the maintenance of a standard with respect to the character of papers and the importance of their technical content which is consistent with the aims and purpose of the Institute. This phase

of the committee's activity has called for painstaking work on the part of competent reviewers selected by the technical committee chairmen from the personnel of their committees or the general membership. Assistance has been rendered to the committee on award of Institute prizes by the grading of each paper when initially reviewed.

Program Diversification and Subject Balance. In the arrangement of technical programs for the national conventions the committee has endeavored to meet the needs of both the specialist and the average member by scheduling a variety of subject matter. The study of the analysis of subject matter presented in papers over a period of years has been continued. Through the results of this study, efforts are made to attain a subject balance in proportion to the occupations and interests of all members. At the last summer convention an entire session was devoted to applications to iron and steel production, and at the winter convention a symposium on magnetic materials was held. Sessions had not been devoted to these subjects for several years.

Technical Conferences. For the benefit of specialists and the younger members, 14 technical conferences devoted to specialized subjects were scheduled during the last summer convention held at Ithaca, N. Y. These conferences were arranged by the chairmen of subcommittees through their respective technical committees. They afforded opportunity for the committees to obtain assistance from individuals, and through the mutual exchange of information in discussion both the committees and the individuals have profited. Three such conferences were held during the 1936 winter convention and were well attended. They dealt with the subjects of network synthesis, sound, and transformers for communication purposes. Arrangements are being made to schedule a number of technical conferences at the forthcoming summer convention to be held at Pasadena, Calif.

An analysis of the papers reviewed by the technical program committee, as shown in table II, when compared with the analysis for the previous year, indicates that the number of papers reviewed and the total number of pages required have remained about the same, as has also the average length of papers. The reviewers of papers have been selective in accepting material, and of the papers presented to the committee for consideration 78 per cent were accepted, some of the papers being returned to authors with suggestions for revision. All discussions have also been reviewed.

Although convention attendance is greatly influenced by the location of conventions, it is gratifying to note that the total attendance for the past year represented a 9.8 per cent increase over that for the previous year, notwithstanding that there was one more District meeting in the corresponding interval during the previous year.

Acknowledgment is extended to the members of the committee, the technical committees, reviewers and members of the headquarters staff for their assistance and co-operation, which have been very helpful in carrying on the work of the committee.

Publication Committee

1935 marked the second year of operation under the unified publication plan adopted by the board of directors in August 1933. As scheduled, ELECTRICAL ENGINEERING has carried monthly to all members of the Institute: (1) the full text of all recommended technical papers, (2) the full text of all recommended discussions of those papers, (3) a few of the special articles and other general interest features that continue to be highly popular among the membership, and (4) regular news reports of Institute and related activities. One of the most popular features this year has been the monthly "message from the president" contributed regularly by President E. B. Meyer.

The TRANSACTIONS is now identical in content with the 12 monthly issues of ELECTRICAL ENGINEERING for the calendar year, and is issued as a single cloth-bound volume, complete with a comprehensive indexing system designed to correlate the technical papers and their associated discussions, and to provide a convenient channel of approach to either or both.

Table II—Analysis of Papers Reviewed by the Technical Program Committee and Attendance at Meetings for the Past Year

April 30, 1935 to April 30, 1936	No. Papers	Total No. Pages	Average Page Length Per Paper	Attendance	Attendance April 30, 1934 to April 30, 1935
National Conventions					
Ithaca, N. Y., June 24–28	39	252 1/2	6 1/2	904	351 Hot Springs, Va., June 25–29
Seattle, Wash., Aug. 27–30	16*	68	5 3/4	269	232 Salt Lake City, Sept. 3–7
New York, Jan. 28–31	59**	364 1/4	6 1/4	1,231	1,114 New York, Jan. 22–25
District Meetings					
W. Lafayette, Ind., Oct. 24–25	14	84 1/2	6	457	571 Oklahoma City, April 24–26
Published in ELEC. ENGG. only	18	84 1/2			337 Worcester, Mass., May 16–18
Yearly totals	141	853 3/4	6 1/4	2,861	2,605

Withdrawn and rejected—22 per cent.
*Includes 4 papers re-presented from summer convention program.
**Includes 1 paper re-presented from Pacific Coast convention program.
These 3 items are not included in column totals.
Percentage increase in attendance—9.8 per cent.

The new publication program has given a broader service to the membership at a substantial reduction in cost, and, judging by comments received from many members, has met with wide approval.

Membership Committee

The membership committee has continued its activities along the lines of the past 2 years as described in previous reports.

As a result of the splendid work of the Section membership committees, co-ordinated by the membership committee, and aided by the entire membership by sending in the names of those thought worthy to be invited to join the Institute, the committee is happy to report a net membership gain for the year, the first since 1931.

The membership statistics for the year are shown in table III, the membership of 14,600 representing a net gain of 331 over last year.

An increase in applications is shown in table IV, and the increased Student enrollment shown in table V should provide for an increase in applications from Students for admission to Associate membership in the coming year.

The number of members reinstated as shown in table VI indicates a decrease, which is good as the the total number is decreasing. This is further shown in tables VII and VIII.

Table IX has been added as a convenient reference for the record of Institute membership.

Table III—Membership Statistics for the Fiscal Year Ending April 30, 1936

	Honorary	Fellow	Member	6-Year Associate	Associate	Total
Membership on April 30, 1935	12	691	3,709	5,632	4,225	14,269
Additions						
Transferred		27	208	621		
New members qualified		3	139	31	1,136	
Former members reinstated		5	38	88	80	
Total	12	726	4,094	6,372	5,441	16,645
Deductions						
Died	1	15	26	46	8	
Resigned		4	48	137	107	
Transferred			24	184	648	
Dropped		8	84	326	379	
Membership on April 30, 1936	11	699	3,912	5,679	4,299	14,600

Table IV—Number of Applications Received From Enrolled Students and From All Others

Year Ending	From Students	From All Others	Total
April 30, 1936	631	946	1,577
April 30, 1935	575	715	1,290
April 30, 1934	467	496	963
April 30, 1933	674	305	979
April 30, 1932	779	612	1,391

Table V—Number of Enrolled Students

April 30, 1936	4,049 (1,991)
April 30, 1935	3,806 (1,983)
April 30, 1934	3,186 (1,548)
April 30, 1933	3,260 (1,494)
April 30, 1932	3,700 (1,624)

Following the number of Students reported for April 30 of each year is indicated within parentheses the number of new applications received during that year; the difference between this number and the reported total, of course, reflects the number of renewals of Student enrollment for the corresponding period.

Table VI—Number of Members in Section Territory Reinstated

August 1, 1935 to April 30, 1936	608
Year beginning August 1, 1934	831
Year beginning August 1, 1933	741
Year beginning August 1, 1932	277
Year beginning August 1, 1931	327

Table VII—Membership of the Institute, April 30, 1936

Of the 14,600 members reported for April 30, 1936, 12,446 are fully paid to April 30, 1936. The balance of 2,154 are divided into the following groups:

1. Members owing dues to April 30, 1935.

Total number of members who have not acted upon resolution of board of directors adopted in January 1936 providing an extension of time for payment of these dues (including 291 members of 6 years' standing or longer who were entitled, upon application, to dues cancellation if unemployed during corresponding fiscal year) 609

Total number of members who obtained dues cancellation to April 30, 1935, because of unemployment, but who have not yet renewed active membership on pro rata basis for current year as provided in resolution of board of directors adopted in January 1936 8

617

2. Members owing dues to April 30, 1936 1,537
(During the period May 1 to 20, 1936, 214 members have paid dues to April 30, 1936, reducing the total to 1,323.)

Table VIII—Memberships Fully Paid

	Membership as of April 30	Number of Members Fully Paid as of April 30	Per Cent Fully Paid
1936	14,600	12,446	85.2
1935	14,269	11,512	80.5
1934	15,230	11,028	72.4
1927 (year of maximum membership)	18,344	16,247	88.5

Table IX—Record of A.I.E.E. Membership

	Total Membership May 1		Total Membership May 1		Total Membership May 1		Total Membership May 1
1884	71	1898	1,098	1911	7,117	1924	16,455
1885	209	1899	1,133	1912	7,459	1925	17,319
1886	250	1900	1,183	1913	7,654	1926	18,158
1887	314	1901	1,260	1914	7,876	1927	18,344
1889	333	1902	1,549	1915	8,054	1928	18,265
1890	427	1903	2,229	1916	8,212	1929	18,133
1891	541	1904	3,027	1917	8,710	1930	18,003
1892	615	1905	3,460	1918	9,282	1931	18,334
1893	673	1906	3,870	1919	10,352	1932	17,550
1894	800	1907	4,521	1920	11,345	1933	17,019
1895	944	1908	5,674	1921	13,215	1934	15,200
1896	1,035	1909	6,400	1922	14,263	1935	14,269
1897	1,073	1910	6,681	1923	15,298	1936	14,600

The committee closes this report with essentially the same statement which closed last year's report, as the same conditions exist. It is not possible in a short space to picture adequately the great amount of work which the Section membership committee chairmen and their committees continually contribute to the membership activities of the Institute. The fact that new applications were received from every Section of the Institute but one attests to the universality of the work and the completeness of the extent of the activities. It is due to the work of these groups combined with the efficient work of the headquarters staff in its manifold forms that the membership figures are good.

Deaths

The following deaths occurred during the year:

Honorary Member: Edwin Wilbur Rice, Jr.

Fellows: Allen H. Babcock, J. Rowland Bibbins, Herbert W. Drake, Orville H. Ensign, Sergius P. Grace, Harry U. Hart, J. Allen Johnson, Charles F. Lacombe, Scott Lynn, Clifford S. MacCalla, Talbot G. Martin, Bryce E. Morrow, Jakob E. Noeggerath, William H. Powell, Hassan C. A. Sabbah.

Members: Lawrence D. Bale, John M. Brodie, M. Bayard Butler, Jr., Louis G. Carpenter, James Clark, Jr., Edward A. Colby, James S. Fitzmaurice, Sataro Fukunaka, Lewis Fussell, William C. Gotshall, Mortimer D. Gould, Jay H. Hall, John J. Howard, Basil Lanphier, Claude W. Mitchell, Arthur J. Pates, Samuel R. Pritchard, Edward A. Quinn, Benjamin S. Read, Malcolm C. Rorty, Frank E. Smith, Robert C. Smith, Frank B. Steele, A. Raymond Tremaine, Otto W. Walter, Franklin W. Wood.

Associates: William Anderson, Theodore Beran, Eskil Berg, Charles N. Black, Eli J. Blake, Charles R. Blanchard, Carl Borgmann, Edgar P. Broe, Arthur D. Buzby, Charles M. Clark, Samuel D. Collett, Kenneth L. Curtis, Delamore L. Davis, William J. M. Davison, Edwin A. Diestler, Kingsley G. Dunn, Marvin N. Fellman, Richard Fleming, Harrison G. Folan, Sumito Fukasawa, James F. Greene, William A. Harding, Frank R. Harvey, Francis R. Healey, Pienchun Huang, Kenneth B. Jones, Dudley H. Keyes, John G. Kleindienst, F. H. Knox, Richard Koch, Frank Land, J. Logan MacBurney, Joseph H. McHugh, James E. Moravec, A. Saunders Morris, Clarence F. Norberg, George W. Oliver, Frederick L. Pierce, David Rasmussen, Paul F. Rauscher, Almon Robinson, Eugene H. Rosenquest, Harley C. Sehulze, Edward K. Shelton, Willard M. Smith, Shanker S. Tatrey, Arthur J. Townsend, Harry W. Turner, Philip V. R. Van Wyck, Norman J. Wilson, J. E. Woodbridge, William Woodrow, Julian E. Woodwell, Aldin W. Wurts.

Board of Examiners

The board of examiners held 11 meetings during the past year, averaging about $2^1/_2$ hours each, and considered 3,459 cases, divided as shown in table X.

Standards Committee

During the past year the standards committee held 4 meetings, averaging about 3 hours each. In addition to the usual routine review of the status of the various standards activities, the following specific projects came up for action: lightning arrester standards and automatic station standards—ordered printed in revised form; fuse standards—a new standard approved for publication; revised report on relay standards—approved for transmission to American Standards Association.

A further development of the "Test Code" undertaking was evidenced in the approval given to suggested codes for "Noise Measurement" and for "Instruments and Measurements."

Among the many A.S.A. sectional committee projects which have as their basis standards submitted to A.S.A. by the Institute, 2 reached a final stage, as follows: rotating electrical machinery standards—approved and published by A.S.A.; standards for railway motors and other rotating electrical machinery on rail cars and locomotives—approved by A.I.E.E. as sponsor. In many cases it was found necessary to revamp A.I.E.E. representation on sectional committees, and in one case, that of scientific and engineering symbols and abbreviations, to reorganize the committee entirely, splitting it into 2 distinct projects.

Two new undertakings of interest arose in which the Institute was asked to participate, the sectional committee on radio-electrical co-ordination and the committee on grounding.

Table X—Applications for Admission and Transfer

Applications for Admission		
Recommended for grade of Associate	1,114	
Re-elected to the grade of Associate	69	
Not recommended	7	1,190
Recommended for grade of Member	127	
Re-elected to the grade of Member	9	
Not recommended	30	166
Recommended for grade of Fellow	4	
Not recommended	2	6
Applications for Transfer		
Recommended for grade of Member	205	
Not recommended	24	229
Recommended for grade of Fellow	27	
Not recommended	1	28
Students		
Recommended for enrollment as Students		1,840
Total		3,459

U.S. National Committee of the I.E.C.

The past year has been notable both for the International Electrotechnical Commission and for the United States national committee of the International Electrotechnical Commission. A plenary meeting of the commission was held in The Hague and Brussels June 18–27, 1935. The electrical fraternity in the United States was honored at the plenary meeting by the election of a distinguished member of the U.S. national committee, James Burke, as president of the International Electrotechnical Commission and by the election of a distinguished former member, Dr. Elihu Thomson, as honorary president.

For many years Mr. Burke has been a member of the U.S. national committee and has made valuable contributions both to the work of the U.S. National committee and the I.E.C. He is one of the very few electrical manufacturers to have been chosen for the presidency of the I.E.C., indicating a trend toward a closer relationship with industry.

Dr. Elihu Thomson was president of the International Electrical Congress of St. Louis in 1904 at which the International Electrotechnical Commission was conceived. He was the second president of the I.E.C. from 1908 to 1911, succeeding Lord Kelvin.

The plenary meetings were held in The Hague and Brussels and were attended by more than 450 delegates from 20 nations. The meeting marked the thirtieth anniversary of the I.E.C., the membership of which now includes 26 nations. The U.S. national committee was represented by the following delegates:

Dr. C. H. Sharp, president of the U.S. National Committee, chief of delegation.
J. W. McNair, secretary of the U.S. National Committee, secretary of delegation.
Dr. A. E. Kennelly, nomenclature; symbols; electric and magnetic magnitudes and units.
L. F. Adams, rating of electrical machinery; shellac; storage batteries; terminal markings.
F. Hodgkinson, steam turbines and internal combustion engines.
K. M. Irwin, steam turbines and internal combustion engines.
C. B. LePage, steam turbines and internal combustion engines.
G. H. Stickney, lamp holders and bases.
H. Lebouteux, aluminum.
W. C. Wagner, standard voltages and currents; overhead lines; electrical measuring instruments.
H. R. Summerhayes, power switchgear; electronic devices; electrical installations on ships.
James Burke, electric traction equipment.
Dr. M. G. Lloyd, overhead lines; electrical measuring instruments.
L. F. Morehouse, radio.
Dr. Sharp and Mr. McNair, wires and cables.

The technical work of the I.E.C. made excellent progress as a result of the plenary meetings, and the following new publications have been issued:

Publication No. 34 (4th edition)—I.E.C. Specifications for Electrical Machinery.
Publication No. 49—Comparison of Rules for Overhead Lines (French edition).
Publication No. 50—International Electrotechnical Vocabulary—Fundamental Definitions.
Publication No. 51—Specifications for Indicating Electrical Measuring Instruments.
Publication No. 52—Rules for the Measurement of Test-Voltage at Power Frequencies in Dielectric Tests by Sphere Gaps.
Publication No. 53—Schedule of Information to be given with Inquiries and Orders for Electrical Machinery.

Among the important accomplishments of the 20 committees of the I.E.C. which met at The Hague and Brussels, the following may be mentioned in the limited space available.

Perhaps the most notable single accomplishment of these meetings was the adoption of the meter-kilogram-second system of absolute and practical units. A complete description of this action, by Dr. Kennelly, chairman of the international committee, will be found on pages 1373–84 of the December 1935, issue of ELECTRICAL ENGINEERING.

Publications 34 and 52, mentioned above, were approved for publication by the committee on rating of electrical machinery. Several sections of the international electrotechnical vocabulary were approved for publication.

Rules for instruments and methods of measurement used in acceptance tests were adopted to complete a series of rules on steam turbines. The scope of the committee's work was extended to include turbines used in industry other than those for turbogenerator sets which had previously been covered.

Specifications for internal combustion engines were tentatively agreed to by the committee covering that subject.

Tentative agreement was reached on standard values for resistivity, density, and temperature coefficient of both hard-drawn and annealed aluminum.

A general outline of the scope of a proposed revision of the international specifications for traction motors was agreed upon.

A report on the tests which have been carried out by an international subcommittee on insulating oils was discussed, and a program of further investigations decided upon.

An international specification for electrical measuring instruments was adopted for circulation to the national committees for approval. It was decided to set up a committee to study the properties and methods of testing electrical insulating materials.

Rules for the marking of the terminals on electrical machinery and apparatus were discussed. European practice is, however, so different from American that the I.E.C. publication will carry both systems.

A revised draft specification for the rating and performance of oil-immersed circuit-breakers is to be circulated.

A committee on electrical installations on ships held its first meeting, and a number of subcommittees were set up with a view to co-ordinating the present practice of the various countries.

An international specification for the testing of high-voltage paper-insulated lead-covered cables was agreed upon for circulation to the national committees for approval.

International specifications for testing of insulators for overhead power lines were approved for submission to the national committees for their comments, as was a general specification for impulse testing.

The next plenary meeting of the International Electrotechnical Commission is scheduled to be held in England in June 1938. In the interim, of course, meetings of a number of the advisory committees will be held.

Committee on Safety Codes

Early in the administrative year, suggestions were received that the committee on safety codes should be more active and take a larger part in the general field of safety work. The matter was taken up by correspondence and the interest manifested resulted in a meeting of the committee in New York on January 29, 1936, at which, in addition to members of the committee, several others prominent in safety work were present by invitation. The majority opinion at this meeting was favorable to expanding the scope of the committee's activities, but the view was expressed that such expansion should be restricted to lines of effort which give definite promise of being useful and also which do not duplicate work which is already being taken care of by other agencies. The committee proposes to submit this question to the board of directors for consideration and decision.

As is customary, the chairman of the committee on safety codes has been designated as the A.I.E.E. representative on the electrical committee of the National Fire Protection Association. As such he has attended to a number of matters which have arisen in reference to the National Electrical Code.

The chairman also represents the Institute on the committee on low voltage hazards, a subsidiary of the National Safety Council, but this assignment has called for no action during the year other than making some inquiries by correspondence.

As the representative of the A.I.E.E. on the National Fire Waste Council, the chairman attended the council's annual meeting at the U.S. Chamber of Commerce in Washington, D. C., on March 27. This was an interesting meeting largely devoted to problems of fire protection in rural areas.

A new joint committee called the American research committee on grounding has recently been organized to investigate technical questions relating to the practice of grounding electrical systems on water and other pipes. Such grounding, while of primary importance from the standpoint of safety to life, has been suspected by water companies and others of having caused trouble by the introduction of harmful currents on the pipes. The new committee which includes representatives of some 15 national societies and other interested organizations, and of which the present chairman of the committee on safety codes is chairman, is undertaking to make such investigations as may be necessary to determine the relevant physical factors and their reactions on current practices and other features of the situation.

Co-ordination Committee

The committee followed the established practice of requesting District and Section officers to submit by January 1 applications for the authorization of any national conventions and District meetings desired in their respective Districts during the calendar year 1937, and a recommended schedule of such meetings will be presented at the meeting of the board of directors to be held on May 25.

Committee on Constitution and By-Laws

During the year, the committee approved for presentation to the board of directors several proposed amendments to the by-laws of the Institute, all of which were approved by the board.

Committee on Legislation Affecting the Engineering Profession

No matters were brought to the attention of the committee.

The licensing of engineers is very active throughout the country and it is important for each member of the Institute fully to protect his interest.

The Institute's Sections can be of service to the membership through meetings at which licensing is discussed and by organizing classes to prepare members for the examinations which would be required in many of the states.

Committee on the Economic Status of the Engineer

The various matters which might otherwise have been acted upon by this committee during the year have seemed to lie definitely within the scopes of activities of American Engineering Council and Engineers' Council for Professional Development. As the chairman of the committee is one of the Institute's representatives upon each of these bodies, and chairman of the delegation to the former, the committee has not acted separately.

Technical Committees

The technical committees, under the leadership of the technical program committee, have continued their efforts to clarify the definitions of scopes of their activities, in order to make definite provisions for effectively covering all the desired ranges of subjects and to eliminate overlapping among the committees.

They have continued their usual activities in the stimulation of the preparation and presentation of desirable papers in their respective fields and in the review of technical papers submitted.

Institute Prizes

Four national prizes and 11 District prizes for papers presented in 1934 were awarded to authors. The national prizes and the North Eastern District prizes were presented at the summer convention at Cornell University, Ithaca, N. Y., and other District prizes were presented at various meetings in the respective Districts. The awards were announced in the 1935 issues of Electrical Engineering for June (page 677), July (page 785), and September (page 1007).

Committee on Award of Columbia University Scholarships

The committee selected for the award of the scholarship placed at the disposal of the Institute, for the class entering upon graduate study in electrical engineering at Columbia University in the fall of 1935, Joseph Leo Dalton of Glenside, Pa. As usual the availability of these scholarships was announced in the February issue of Electrical Engineering and in a circular letter to the counselors of all Student Branches of the Institute.

Edison Medal

The Edison Medal, which is awarded by a committee composed of 24 members of the Institute, was, for 1935, awarded to Dr. Lewis B. Stillwell "for distinguished engineering achievements and his pioneer work in the generation, distribution, and utilization of electric energy," and was presented on January 29, 1936, during the winter convention. The medal may be awarded annually "for meritorious achievement in electrical science, electrical engineering, or the electrical arts."

John Fritz Medal

The John Fritz Medal board of award, composed of representatives of the national societies of civil, mining, mechanical, and electrical engineers, awarded the thirty-second medal (for 1936) to Dr. W. F. Durand for notable achievement "as authority in hydrodynamic and aerodynamic science, and in its practical application; outstanding leader in research and in engineering education."

Lamme Medal

The Lamme Medal committee awarded the medal for 1935 to Dr. Vannevar Bush "for his development of methods and devices for application of mathematical analysis to problems of electrical engineering." Arrangements are being made for the presentation of the medal at the annual summer convention at Pasadena, Calif., June 22–26, 1936. The medal may be awarded annually to a member of the A.I.E.E. "who has shown meritorious achievement in the development of electrical apparatus or machinery."

Washington Award

The Washington Award for 1936 was bestowed upon Dr. Charles F. Kettering, "for his high achievements in guiding industrial research toward the greater comfort, happiness, and safety of mankind in the home and on the highway," and was presented to him on February 25, 1936. This award may be made annually to an engineer by the commission of award composed of 9 representatives of the Western Society of Engineers and 2 each of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

Alfred Noble Prize

This prize, established in 1929, consists of a certificate and a cash award of $500 from the income from a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past-president of the A.S.C.E. and of the Western Society of Engineers. It may be made to a member of any of the co-operating societies, A.S.C.E., A.I.M.E., A.S.M.E., A.I.E.E., or W.S.E., for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. No award was made in 1935.

Iwadare Foundation Committee

The fourth lecturer to visit Japan was Dr. Dugald C. Jackson of Massachusetts Institute of Technology. Professor Jackson arrived in Japan about the middle of November of last year and, during the several weeks of his visit, addressed audiences at many of the leading universities. His lectures were very instructive and interesting, and were well attended.

The seventh Iwadare Fellow to visit the United States was Professor Hideo Yamashita of the faculty of engineering of Tokyo Imperial University. His visit began in May of last year.

Joint Activities

A special joint dinner meeting of the officers and directors of the national societies of civil, electrical, mechanical, and mining and metallurgical engineers, and of the several joint organizations was held at the Engineers' Club, New York, May 20, 1935. Comprehensive but concise statements concerning the scope of activities of United Engineering Trustees, Inc., Engineering Societies Library, Engineering Foundation, American Standards Association, Division of Engineering and Industrial Research of National Research Council, Employment Service, American Engineering Council, and Engineers' Council for Professional Development were presented. These were published essentially in full in Electrical Engineering for July 1935, pages 788–94.

Employment Service

The Institute co-operates with the national societies of civil, mining, and mechanical engineers in operation of the Engineering Societies Employment Service with its main office in the Engineering Societies Building, New York. Offices are operated in Chicago and San Francisco also. In addition to the societies named, others co-operate in certain of the offices as follows: New York—Society of Naval Architects and Marine Engineers; Chicago—Western Society of Engineers; San Francisco—California Section of the American Chemical Society; and the Engineers' Club of San Francisco.

The New York office has co-operated closely with the Professional Engineers Committee on Unemployment which was organized in the fall of 1931 by the local Sections of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

The service is supported by the joint contributions of the societies and their individual members who are benefited. In addition to the publication of the employment service announcements monthly in Electrical Engineering, weekly subscription bulletins are issued for those seeking positions.

An analysis of this employment service as reported to the national societies is given in table XI.

American Engineering Council

During 1935, the A.I.E.E. has continued to support aggressively the American Engineering Council. The Institute is represented officially on the assembly of Council by 5 delegates as follows:

C. O. Bickelhaupt, assistant vice president, American Telephone and Telegraph Company, 195 Broadway, New York, N. Y.

F. J. Chesterman, vice president, Bell Telephone Company of Pennsylvania, 416 Seventh Ave., Pittsburgh, Pa.

Wm. McClellan, president, Potomac Electric Power Company, 10th and E Streets, N.W., Washington, D. C.

E. B. Meyer, chief engineer, electric engineering department, Public Service Electric and Gas Company, 80 Park Place, Newark, N. J.

C. E. Stephens, vice president, Westinghouse Electric and Manufacturing Company, Room 1628, Rockefeller Plaza, New York, N. Y.

These representatives have been active not only on the public affairs committees of Council but share with the other engineering societies the responsibility of the executive committee. Messrs. Bickelhaupt, McClellan, and Stephens have served as members of this committee for the year 1935, and at the annual meeting of American Engineering Council, held January 10 and 11, F. J. Chesterman, chairman of the public affairs committee of Council, was made *ex-officio* member of the executive committee.

The year 1935 has been marked by a growing desire on the part of all the professional engineering groups to join in a spirit of unity to advance the engineer's relations both to public affairs and affiliated questions of professional interest to the engineer. Evidences of this spirit of united action were exhibited at the annual meeting of Council in January of this year, where the work of committees and the activities of Council were reviewed. A report of the annual meeting was published in the February issue of ELECTRICAL ENGINEERING, page 215.

Table XI—Analysis of Employment Service

Month	Men Registered				Men Placed			
	New York	Chicago	San Francisco	Total	New York	Chicago	San Francisco	Total
1935								
May	100	56	59	215	45	12	13	70
June	175	81	92	348	43	22	20	85
July	131	86	49	266	47	25	19	91
August	110	56	46	212	54	31	14	99
September	94	97	45	236	75	27	21	123
October	79	96	64	239	76	43	32	151
November	67	74	46	187	72	24	20	116
December	88	44	50	182	60	20	25	105
1936								
January	117	69	49	235	59	26	13	98
February	160	49	57	266	50	25	13	88
March	145	62	63	270	60	30	37	127
April	147	59	77	283	57	45	36	138
Total	1,413	829	697	2,939	698	330	263	1,291

Under a new membership plan launched earlier in 1935, the number of local members of American Engineering Council was practically doubled, bringing the total members of Council from 23 to 42 as of January 1, 1936. At the annual meeting, other organizations indicated their desire to join in the work of Council so that this growth will probably continue in the year 1936.

By arrangement between the executive secretary of American Engineering Council and the secretaries of the national member organizations, a monthly digest of the activities of Council is presented in the news sections of each issue of ELECTRICAL ENGINEERING.

During 1935, the federal government continued with the development of emergency plans and programs projected to relieve unemployment and the committees and staff of American Engineering Council were called into consultation by many executive departments of the government, not only to confer as to detailed planning and carrying out of such enterprises, but with regard to such questions as engineer personnel, conditions of employment, compensation, etc. In co-operation with the Engineering Societies Employment Service of New York, the staff of Council gave a very considerable portion of its time on an emergency basis to personnel and employment problems. While these questions are not normally a part of the work of American Engineering Council, pressure within the federal departments for aid in these matters made it essential that Council serve in that capacity for the period of the emergency.

During the year, a new plan of handling the public affairs committee of American Engineering Council, under the chairmanship of F. J. Chesterman, a member of the A.I.E.E., was inaugurated and at the annual meeting of Council, the plan of the public affairs committee was adopted as a general plan for all committee activities of Council. In brief, the chairmen of special committees of public affairs, become members of the general committee on public affairs under a general chairman. This plan has been extended for the year 1936 by setting up 4 groups of committees to function with the staff of Council. These groups of committees are:

a. The committee on public affairs.
b. The committee on engineering economics.
c. The committee on programs for united action of member organizations.
d. The American Engineering Council operating committees.

The functions of the committee on public affairs and the operating committees are perhaps self-evident. The committee on engineering economics is established as a fact finding agency to inquire into problems in the public interest in which the engineer shares the economic consequences of his work with other professional and business groups. One of the subcommittees of the general committee on engineering economics, the committee on relation of consumption, production, and distribution, of which Ralph E. Flanders is chairman, made its third and final report to Council and it was voted to publish this report as a sort of catechism of American economic philosophy and practice. This report will shortly be published and distributed, and should constitute a real contribution of engineers to the discussion of present-day economic and social problems.

The functions of the committee for united action of member-organizations grow out of the expressed wish of one or more member-organizations of Council to explore fields for common action, and in co-operation with committees already established by member-organizations, brings about more united action. The subcommittees carry out the desire for united action on objectives several times emphasized at the annual meeting. The new committee embraces in part an earlier committee of Council known as the engineering and allied technical committee.

One of the fact finding undertakings which comes within the scope of this committee is the survey of the engineering profession undertaken with the co-operation of many engineering societies by the

Bureau of Labor Statistics under the sponsorship of American Engineering Council. This is by far the largest and probably the most important survey of the engineering profession. More than 60,000 questionnaires were received from a mailing list of some 170,000 names and, with this very large sample, the Bureau of Labor Statistics will shortly begin publication of a series of analyses showing the background of education, the position held by the engineer, compensation distribution by industry and government, and a score of other interesting sidelights which should provide a basis for intelligent discussion for the engineer's place in the community and his economic and professional status.

A conference of secretaries of engineering societies was held just preceding the annual meeting of Council, at which there were present representatives of some 45 national, state, and local engineering societies. The results of this conference were also reported in the February issue of ELECTRICAL ENGINEERING.

American Engineering Council enters its sixteenth year with the good-will of its member-organizations and a sense of opportunity to capitalize on the spirit of unity in the profession to follow the objectives long sought by engineers in common. There is particularly an opportunity for the local Sections of the A.I.E.E. to co-operate with the sections of other national societies and with the local engineering organizations on questions of common interest to the profession not concerned with questions of technology, and it is hoped that this movement to coordinate engineering opinion locally on questions of public affairs may be extended and broadened during the coming year.

The following officers were elected at the annual meeting: Dean A. A. Potter, president; C. O. Bickelhaupt, vice president; J. S. Dodds, vice president; Ralph Flanders, vice president; A. J. Hammond, vice president; C. E. Stephens, treasurer.

United Engineering Trustees, Inc.

During the year, this organization as an agency of the founder societies, made additional improvements in the facilities of the Engineering Societies Building, particularly in the auditorium, revised its by-laws, and performed other duties necessary to maintain the building and administer the funds in its custody, including those of its departments, The Engineering Foundation and The Engineering Societies Library.

The United Engineering Trustees, Inc., and the secretaries of the founder societies arranged for a joint dinner meeting of the officers and boards of the societies and of their joint organizations held on May 20, 1935, for the purpose of establishing a better understanding among these individuals of the many important activities conducted by these jointly operated agencies. See heading "Joint Activities" above.

This organization continued as treasurer of the Professional Engineers' Committee on Unemployment, of the local sections of 4 national engineering societies, and became treasurer of the Engineers' Council for Professional Development.

Abstracts of the annual report of the United Engineering Trustees, Inc., were published in the December 1935 issue of ELECTRICAL ENGINEERING, pages 1419–20.

Engineering Foundation

This department of the United Engineering Trustees, Inc., supplied financial support, during 1935, for many research projects sponsored by the founder societies, notably the following: A.S.C.E.—earths and foundations. A.I.M.E.—critical review of world's literature on alloy irons and alloy steels since 1890, and barodynamic research. A.S.M.E.—critical pressure steam boilers, fluid meters, boiler feed water, cottonseed processing, strength of gear teeth, cutting of metals, effects of temperature upon properties of metals. A.I.E.E.—welding with pure iron electrodes, and organization of a comprehensive program of research in all branches of welding under the supervision of the Welding Research Committee (American Welding Society, joint sponsor).

The Foundation also assisted the Engineers' Council for Professional Development, the Personnel Research Federation, and an investigation of the Engineering Index.

An abstract of the annual report of The Engineering Foundation was published in the December 1935 issue of ELECTRICAL ENGINEERING, page 1421.

Engineering Societies Library

The Engineering Societies Library, which was formed by combining the separate libraries of the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and the preparation of a composite card catalog, has been expanded as a single engineering library, which probably constitutes the best collection of this type of literature in the country. With its 145,000 volumes, about 1,200 periodicals in many languages received regularly, and its staff thoroughly experienced in rendering all library services required by engineers, by mail, as well as in the library, it has continued, despite drastic reductions in its budget, to afford highly appreciated assistance to increasing numbers of members of the co-operating societies. Special services rendered include: photoprints, abstracts, translations, bibliographies, searches, book loans by mail, etc.

An abstract of the annual report of the library was published on page 1420 of ELECTRICAL ENGINEERING for December 1935.

Engineers' Council for Professional Development

This council, which was formally organized in 1932 for the enhancement of the professional status of the engineer, includes 3 representatives of each of the 7 participating organizations: the national societies of chemical, civil, electrical, mechanical, and mining

and metallurgical engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners.

The principal activities of E.C.P.D. include the guidance of young individuals thinking of entering the engineering field, the accrediting of engineering schools, encouragement and assistance to individuals continuing their engineering and cultural training during several years after graduation, and the establishment of suitable standards for indicating the attainment of the status of an engineer.

Detailed information regarding the recommendations submitted by E.C.P.D. to the participating organizations and other features of its activities were published during the year in numerous issues of ELECTRICAL ENGINEERING.

Representatives

The Institute has continued its representation upon many joint committees and national bodies, with which it co-operates in a wide range of activities of interest and importance to engineers and others.

A complete list of representatives was published in the September issue of ELECTRICAL ENGINEERING and in the 1936 Year Book.

Finance Committee

The committee, as usual, recommended a detailed budget to the board of directors, passed upon the expenditures for various purposes, made recommendations regarding delinquent members, and performed the other duties prescribed for it in the constitution and by-laws.

Haskins and Sells, certified public accountants, have audited the books, and their report follows.

Respectfully submitted for the board of directors.

H. H. HENLINE
National Secretary

May 25, 1936

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

22 EAST 40TH STREET
NEW YORK

May 20, 1936.

American Institute of Electrical Engineers,
33 West 39th Street,
New York.

Dear Sirs:

We have made an examination of your statement of financial condition as of April 30, 1936, and of your recorded cash receipts and disbursements for the year ended that date. In connection therewith, we examined or tested your accounting records and other supporting evidence in a manner and to the extent which we considered appropriate in view of your system of internal accounting control. We present the following financial statements:

Balance Sheet, April 30, 1936 (Exhibit A).
Property and Restricted Funds Securities, Less Reserve for Bonds of Doubtful Value (Schedule 1).

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1936 (Exhibit B).

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1936 (Exhibit C).

In accordance with the terms of our engagement the members and other debtors were not requested to confirm to us the amounts receivable from them at April 30, 1936, and, in accordance with the usual practice of the Institute, no provision has been made for dues which may prove to be uncollectible.

In our opinion, based upon such examination and subject to the foregoing, the accompanying Exhibit A fairly presents your financial condition at April 30, 1936, and the accompanying Exhibits B and C set forth your recorded cash receipts and your disbursements of funds as indicated during the year ended that date.

Yours truly,

HASKINS AND SELLS

Balance Sheet, April 30, 1936

Exhibit A

ASSETS

Property Fund Investments:		
One-fourth interest in real estate and other assets of United Engineering Trustees, Inc., exclusive of Trust Funds	$496,948.48	
Equipment:		
Library—Volumes and fixtures	37,296.37	
Office furniture and fixtures (less reserve for depreciation, $25,263.33)	8,392.71	
Works of art, etc.	3,001.35	
Securities—At cost (market quotation value, $10,362.02)—Schedule 1	10,042.53	
Cash (see Exhibit C)	22.47	
Total property fund investments		$555,703.91
Restricted Fund Investments:		
Securities—At cost, less reserve for bonds of doubtful value (market quotation value, $195,227.63)—Schedule 1	$197,453.52	
Cash (see Exhibit C)	5,579.59	
Accrued interest receivable	217.92	
Total restricted fund investments		203,251.03
Current Assets:		
Cash	$ 48,367.77	
Accounts receivable:		
Members—For dues	19,285.39	
Advertisers	149.00	
Miscellaneous	2,107.45	
Accrued interest on investments	2,719.49	
Inventories:		
TRANSACTIONS, etc.	2,269.75	
Text and cover paper	4,542.96	
Work in process (May issue of ELECTRICAL ENGINEERING)	3,229.46	
Membership Badges	1,019.90	
Total current assets		83,691.17
Total		$842,646.11

LIABILITIES

Property Fund Reserve		$555,703.91
Restricted Fund Reserves:		
Reserve Capital Fund	$182,860.72	
Life Membership Fund	9,635.07	
International Electrical Congress of St. Louis Library Fund	5,121.19	
Lamme Medal Fund	4,607.63	
Mailloux Fund	1,026.42	
Total restricted fund reserves		203,251.03
Current Liabilities—Accounts Payable		10,100.90
Deferred Income:		
Dues received in advance	$ 4,294.42	
Entrance fees and dues advanced by applicants for membership	992.00	
Deferred credits and other unallocated receipts	672.78	
Subscriptions for TRANSACTIONS received in advance	44.58	
Reserve for prepaid subscriptions for ELECTRICAL ENGINEERING	8,000.00	
Total deferred income		14,003.78
Surplus		59,586.49
Total		$842,646.11

Property and Restricted Funds Securities, Less Reserve for Bonds of Doubtful Value, April 30, 1936

Exhibit A, Schedule 1

	Face Value of Bonds or Number of Shares of Stock	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
Railroad Bonds:								
Alleghany Corporation 20-year collateral trust convertible 5%, due 1949	$15,000.00		$ 10,627.50					$ 10,627.50
Baltimore & Ohio Railroad Company 6% refunding and general mortgage series C, due 1995	12,000.00		8,940.00			$4,330.00		13,270.00
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	3,000.00		1,477.50					1,477.50
Chesapeake & Ohio Railway Company 4½% refunding and improvement mortgage, due 1993	1,000.00				$1,122.50			1,122.50
Chicago, Burlington & Quincy Railroad Company 4%, due 1958	5,000.00			$4,868.75				4,868.75
Chicago, Burlington & Quincy Railroad Company 5% first and refunding mortgage series A, due 1971	1,000.00		1,010.00					1,010.00
Chicago & Erie Railroad Company 5% first mortgage, due 1982	1,000.00		1,105.00					1,105.00
Chicago & Northwestern Railway Company 6½%, due March 1, 1936	9,000.00		7,202.50					7,202.50
Cleveland Union Terminals Company 5% sinking fund series B, due 1973	4,000.00	$ 4,010.00						
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974 (certificates of deposit)	10,000.00		9,818.75					9,818.75
New York Central Railroad Company 5% refunding and improvement mortgage series C, due 2013	6,000.00		5,742.50					5,742.50
Northern Pacific Railway Company 6% refunding and improvement mortgage series B, due 2047	10,000.00		10,962.50					10,962.50
Pennsylvania Railroad Company 30-year secured serial 4%, due 1944	6,000.00		5,337.50		1,067.50			6,405.00
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950 (certificates of deposit)	6,000.00		5,497.50					5,497.50
Western Pacific Railroad Company 5% series A, due 1946	15,000.00		7,225.00					7,225.00
Total railroad bonds—(Forward)		$ 4,010.00	$ 74,946.25	$4,868.75	$2,190.00	$4,330.00		$ 86,335.00

Property and Restricted Funds Securities, Less Reserve for Bonds of Doubtful Value, April 30, 1936

xhibit A, Schedule 1 (Concluded)

	Face Value of Bonds or Number of Shares of Stock	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
OTAL RAILROAD BONDS—(Forward)		$ 4,010.00	$ 74,946.25	$4,868.75	$2,190.00	$4,330.00		$ 86,335.00
ublic Utility Bonds:								
merican Gas & Electric Company 5% debenture, due 2028	$10,000.00		$ 10,656.25					$ 10,656.25
eorgia Power Company first and refunding mortgage 5%, due 1967	10,000.00		9,725.00					9,725.00
ew York Telephone Company $4^1/_2$%, due 1939	1,000.00						$1,000.00	1,000.00
hiladelphia Company secured 5% series A, due 1967	10,000.00		10,000.00					10,000.00
hawinigan Water & Power Company $4^1/_2$% first mortgage and collateral trust sinking fund series A, due 1967	5,000.00		4,581.25					4,581.25
exas Electric Service Company 5% first mortgage, due 1960	10,000.00		9,838.75					9,838.75
nited Light & Power Company $5^1/_2$% first lien and consolidated mortgage, due 1959	5,000.00		4,975.00					4,975.00
Total public utility bonds			$ 49,776.25				$1,000.00	$ 50,776.25
ndustrial and Miscellaneous Bonds, Etc.:								
ethlehem Steel Company 5% purchase and improvement mortgage sinking fund, due July 1, 1936	$ 5,000.00		$ 5,033.75					$ 5,033.75
idelity Union Title and Mortgage Guaranty Company first mortgage certificates (on property 75–79 Prospect Street, East Orange, N. J.), 4%, due 1944	14,663.00	$ 977.53	13,685.47					13,685.47
nternational Match Corporation 5% convertible debentures, due 1941 (certificate of deposit)	2,848.05		2,728.05					2,728.05
nternational Securities Corporation of America 5% debentures, due 1947	6,000.00		6,095.00					6,095.00
ew York Steam Corporation 6% first mortgage, due 1947	10,000.00		10,837.50					10,837.50
nited States Rubber Company 5% first and refunding mortgage series A, due 1947	2,000.00		1,915.00					1,915.00
Total industrial and miscellaneous bonds, etc		$ 977.53	$ 40,294.77					$ 40,294.77
unicipal Bonds:								
ity of Detroit public lighting refunding $4^1/_2$% A, due 1945	$10,000.00		$ 10,262.50					$ 10,262.50
ity of Union City, New Jersey, improvement bond of 1929 $4^3/_4$%, due 1945	10,000.00		10,154.50					10,154.50
ew York City $4^1/_2$% corporate stock, due 1957	2,000.00				$2,204.05			2,204.05
Total municipal bonds			$ 20,417.00		$2,204.05			$ 22,621.05
apital Stocks:								
ommonwealth Edison Company	12 shares		$ 2,892.00					$ 2,892.00
ommercial Investment Trust Corporation $4^1/_4$% preferred series of 1935	100 shares		10,100.00					10,100.00
onsolidated Edison Company of New York, Inc., $5.00 cumulative preferred	30 shares	$ 3,060.00						
ublic Service Corporation of New Jersey, $5.00 preferred	30 shares		2,958.75					2,958.75
nited Gas Improvement Company, $5.00 preferred	30 shares	1,995.00	997.50					997.50
Total capital stocks		$ 5,055.00	$ 16,948.25					$ 16,948.25
Total		$10,042.53	$202,382.52	$4,868.75	$4,394.05	$4,330.00	$1,000.00	$216,975.32
ess Reserve for Bonds of Doubtful Value:								
entral of Georgia Railway Company 5% consolidated mortgage, due 1945	$ 3,000.00		$ 1,477.50					$ 1,477.50
lorida East Coast Railway Company 5% first and refunding mortgage series A, due 1974	10,000.00		9,818.75					9,818.75
nternational Match Corporation 5% convertible debentures, due 1941	2,848.05		2,728.05					2,728.05
t. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950	6,000.00		5,497.50					5,497.50
Total reserve for bonds of doubtful value			$ 19,521.80					$ 19,521.80
Total securities, less reserve		$10,042.53	$182,860.72	$4,868.75	$4,394.05	$4,330.00	$1,000.00	$197,453.52
otal Property Fund Securities		$10,042.53						
otal Restricted Fund Securities			$182,860.72	$4,868.75	$4,394.05	$4,330.00	$1,000.00	$197,453.52

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1936

Exhibit B

Cash on Deposit, May 1, 1935, With the National City Bank of New York		$ 54,815.62
Receipts:		
Dues (including $74,676.00 allocated to ELECTRICAL ENGINEERING subscriptions)	$178,424.03	
Advertising	24,363.76	
TRANSACTIONS subscriptions	7,424.60	
ELECTRICAL ENGINEERING subscriptions	12,956.16	
Miscellaneous publications, etc.	5,882.01	
Students' fees	9,447.75	
Entrance fees	6,341.00	
Membership badges	1,546.50	
Transfer fees	1,160.00	
Interest on investments, less purchased interest	7,405.12	
Miscellaneous	972.14	
Total receipts		255,923.07
Total		$310,738.69
Disbursements:		
Publication expense:		
ELECTRICAL ENGINEERING	$ 72,955.18	
TRANSACTIONS	3,729.82	
Year Book	6,245.33	
Miscellaneous	2,459.80	
Administrative expenses	42,161.72	
Institute Sections	29,004.17	
Institute meetings	10,902.36	
Institute Branches	2,560.35	
American Engineering Council	10,000.00	
Traveling expenses:		
Board of Directors	4,344.27	
Branch Counselors	4,396.20	
Geographical districts:		
Executive Committees	1,238.00	
Vice Presidents	359.63	
National Nominating Committee	652.06	
President's Special Appropriation	1,574.45	
Forward	$192,583.34	$310,738.69

Total—(Forward)		$310,738.69
Disbursements—(Forward)	$192,583.34	
United Engineering Trustees, Inc.:		
Library assessment	10,929.52	
Building assessment	5,882.28	
Standards Committee	5,014.95	
Membership Committee	7,226.02	
Engineering Societies Employment Service	3,225.04	
American Standards Association	1,000.00	
Membership badges	1,638.21	
Retirement salary	2,700.00	
Finance Committee	1,400.00	
United States Committee of International Commission on Illumination	300.00	
Geographical district—Paper prizes	211.36	
John Fritz Medal	63.37	
Technical Committees	207.96	
Headquarters Committee	337.30	
Code Committee	60.00	
Edison Medal Committee	162.01	
Transfer to reserve capital fund	29,429.56	
Total disbursements		262,370.92
Cash on Deposit, April 30, 1936, With the National City Bank of New York		$ 48,367.77

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1936

Exhibit C

		Restricted Funds					
	Property Fund (Equipment Replacements)	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total Restricted Funds
Cash on Deposit May 1, 1935, With East River Savings Bank and National City Bank of New York	$22.47	$ 630.78	$4,757.52	$1,650.82	$218.13	$ 9.92	$ 7,267.17
Receipts:							
Interest on bonds			$ 200.00	$ 179.75	$240.00	$45.00	$ 664.75
Interest on bank balances			129.93				129.93
Proceeds from sale and redemption of bonds		$59,789.16		1,103.32			60,892.48
Life membership fee			271.31				271.31
Transfer from general fund		29,429.56					29,429.56
Total receipts		$89,218.72	$ 601.24	$1,283.07	$240.00	$45.00	$91,388.03
Total	$22.47	$89,849.50	$5,358.76	$2,933.89	$458.13	$54.92	$98,655.20
Disbursements:							
Annual withdrawal authorized in by-laws			$ 625.77				$ 625.77
Bronze and gold replicas of Lamme Medal					$280.50		280.50
Purchase of bonds and stock		$89,849.50		$2,215.38			92,064.88
All other disbursements				53.46		$51.00	104.46
Total disbursements		$89,849.50	$ 625.77	$2,268.84	$280.50	$51.00	$93,075.61
Cash on Deposit, April 30, 1936, With East River Savings Bank and National City Bank of New York	$22.47		$4,732.99	$ 665.05	$177.63	$ 3.92	$ 5,579.59

A Cold-Cathode Arc-Discharge Tube (*From page 794*)

potential obtained from the spark coil is applied to a conventional external starting electrode and causes the formation of a cathode spot. The mercury tube can be started at the desired instant by applying the proper voltage to the grid of the cold-cathode arc-discharge tube. Phase control circuits can be used in the grid circuit of the latter to start a mercury lamp at some predetermined point of the 60 cycle wave.

The circuit shown in figure 5 serves as an audio frequency oscillator from which considerable power may be taken. The voltage across the tube has a saw-tooth form with an exceedingly sharp wave front, and is suitable for purposes requiring a low frequency fundamental combined with many higher harmonics. This type of output voltage may be used to produce a sweep voltage for a cathode-ray oscillograph.

References

1. Hot-Cathode Thyratron, A. W. Hull. *Gen. Elec. Rev.*, v. 32, 1929, April, p. 213–23, and July, p. 390–99.

2. Mercury Arc Power Rectifiers (a book), O. K. Marti and Harold Winograd. McGraw-Hill Book Company, New York, N. Y., 1930, p. 211. Also, Mercury Arc Rectifiers and Circuits (a book), D. C. Prince and F. B. Vogdes. McGraw-Hill Book Company, New York, N. Y., 1927, p. 39.

3. Stroboscopic-Light High-Speed Motion Pictures, H. E. Edgerton and K. J. Germeshausen. Society of Motion Picture Engineers *Jl.*, v. 23, Nov. 1934, p. 284–98.

4. A New Method for Initiating the Cathode of an Arc, Joseph Slepian and L. R. Ludwig. A.I.E.E. Trans., v. 52, June 1933, p. 693–8.

5. The Grid Glow Tube Relay, D. D. Knowles. *Elec. Jl.*, v. 25, April 1928, p. 176–8.

6. The Theory of the Grid Glow Tube, D. D. Knowles. *Elec. Jl.*, v. 27, Feb. 1930, p. 116–20.

7. The Stroboglow, W. E. Bahls and D. D. Knowles. *Elec. Jl.*, v. 28, April 1931, p. 250–3.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 28 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the sessions on synchronous machines, communication, transportation, protective devices, electrical machinery, and electrophysics at the 1936 A.I.E.E. winter convention, New York, N. Y., January 28–31. Other discussion of winter convention papers will be published in a later issue. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Load Losses in Salient Pole Synchronous Machines

Discussion of a paper by E. I. Pollard published in the December 1935 issue, pages 1332–40, and presented for oral discussion at the synchronous machines session of the winter convention, New York, N. Y., January 29, 1936.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Since in synchronous machines the load losses have been based for a great many years on the short-circuit test with full load current, and since this method of determining load losses is included in the various codes, it is of course very desirable to have such a complete analysis of the losses obtaining during the short-circuit test as that given in this paper. Designers in particular should find this of great interest because their guaranties are based on such tests.

The paper is also of interest in that it gives in table II the segregation of the various losses. A review of these figures indicates that, except for some of the smaller machines, those losses which under the short-circuit test are the same as under actual load (that is, the eddy losses, losses in the supporting end ring, and the losses in the end bells) represent in some cases nearly half of the total losses, and in others considerably more. In view of this, any error in the remaining losses which may exist because the conditions applying to them during the short-circuit test differ from the conditions under load, will not unduly influence the correctness of the total load losses found from the short-circuit test. In other words, it appears that in large synchronous machines the established method of testing load losses will give reasonably correct results, which in turn is fortunate, because the input-output tests are impracticable for large machinery.

This same condition, however, does not hold true in the case of smaller machines, as, for instance, induction motors of 50 horsepower or less, for which the short-circuit test with d-c excitation has been suggested at times. In these smaller motors it will frequently be that the eddy current and similar losses which depend upon load current only are a negligible part of the total load losses. It would then be a mistake to assume that the short-circuit tests would yield results for load losses that are even reasonably close to those obtained under actual loads.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents for the first time a method of calculating all of the important elements in the load loss of synchronous machines. This type of analysis is not only very valuable in predetermining the losses in new designs, but also indicates how these extra losses may be reduced.

The derivation of the formulas was necessarily based on a number of simplifying as-

sumptions and it is desirable to check them by test. Since a number of the components of the loss, such as the rotor surface and damper winding loss, cannot be measured directly, the measurement of total load loss must be used as a check. It might seem that a measurement of only the total loss gives no indication of the accuracy of the formulas for the individual components, but in the wide range of machines calculated and tested different factors predominated, so that good agreement over the whole range indicates reasonable accuracy of the various components.

It was originally intended to include the derivation of the end bell loss in another paper, but it may be well to indicate the general method here. If it is assumed that the induced currents in the end bell have a negligible effect on the flux distribution, it is possible to obtain an approximate 3 dimensional flux plot of the end zone flux. This may be done by plotting the field in 2 views, one in a plane through the axis of the machine and another in the plane of the end winding. It is necessary to correct each field to allow for the spreading of the flux tubes in the other dimension.

Since considerable effort is involved in obtaining accurate 3 dimensional fields, the correction factor for the spread of the flux in the plane of the winding was incorporated in the curves. It is then necessary only to determine a permeance factor (λ_e) by a 2 dimensional flux plot in a plane through the axis. When the total flux entering the end bell is determined, the distribution may be estimated by plotting another field in the plane of the end bell, making use of the fact that the ampere-turns per inch are proportional to the square root of the flux per inch. The watts for each element of end bell surface may then be calculated using Rosenberg's or Stienmetz's formulas for loss from flux traveling in the surface of solid iron.

The ampere-turns resulting from induced currents are found to be practically negligible compared with the applied ampere-turns for normal currents, as was originally assumed. However, a correction for this may be made by plotting the field due to the induced currents and determining the loss from the resultant flux.

The distribution of the flux and loss was found to be quite similar in different arrangements of end bells, hence it was possible to calculate an effective area $A_{ie} = 3.5\ \tau_d$ by which the maximum loss density could be multiplied to give the total loss. The loss density was plotted as a function of the effective ampere conductors per inch to give the curves shown in the paper.

Segregation of Losses in Single Phase Induction Motors

Discussion and author's closure of a paper by C. G. Veinott published in the December 1935 issue, pages 1302–06, and presented for oral discussion at the synchronous machines session of the winter convention, New York, N. Y., January 29, 1936.

A. Van Niekerk (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author describes how the motor constants can be determined from a no load run and a locked rotor test. It would be well to emphasize that the locked rotor data at full voltage should be derived from a test made with normal current in the stator (main) winding, in order to prevent the reactances eventually calculated from these data from being too low on account of saturation of leakage paths at current values higher than normal.

Of great importance is the question of whether or not the value of the rotor resistance obtained from a locked test is sufficiently accurate to be used in performance and loss calculations, and it is believed that this question should be answered conclusively before any recommendations are made in a future test code. The author uses the locked value because presumably the actual rotor resistance cannot be computed directly from a load test. But in view of the fact that the "A.I.E.E. Induction Motor Standards" and the "Proposed A.I.E.E. Test Code for Polyphase Induction Machines" stipulate that in working up the performance of a polyphase motor the rotor resistance as determined from a load test should be used whenever possible, it cannot be stated *a priori* that in the case of a single phase motor the use of the locked rotor resistance value will lead to satisfactory results, and therefore an investigation of the merits and limitations of any method involving this use seems highly desirable.

The locked rotor resistance of a polyphase motor with an ordinary squirrel cage rotor is in general higher than the running value, on account of skin effect in the cage bars, and for this same reason the locked reactance is slightly less than the running reactance, althought the change in reactance is usually small. In the case of a single phase motor the situation is somewhat different; when the motor is running, the resistance for the positive sequence rotor currents (which have a very low frequency) is the "true" rotor resistance r_2, while for the negative sequence rotor currents (which have about twice line frequency) the resistance has a somewhat higher value k_2r_2. At standstill, the positive and negative sequence rotor currents both have line frequency, and the effective rotor resistance has the locked value k_1r_2, k_1 being greater than unity and smaller than k_2. Veinott shows in his paper how k_1r_2 is determined from a locked test, and he subsequently uses this value of k_1r_2 in computing the rotor copper loss. As pointed out before, the correctness of the latter method can be established only by a detailed investigation in combination with experiments; it is certain, however, that when k_1r_2 is substituted for the rotor resistance in the motor equations, the calculated values of the slip at given loads will in general be much higher than the measured ones. If, for instance, in the case of the 1/6-horsepower 6-pole 60-cycle motor referred to in the paper the stator input is figured for $s = 0.033$, it is found to amount to about 80 per cent of the input measured during the brake test, indicating that the computed full load slip will be roughly 25 per cent higher than the measured value.

The actual situation is this: The performance of the rotor is determined largely by the rotor resistance r_2; that is, it does not depend to a great extent on k_2, although the rotor copper losses do. It is in connection herewith that r_2 can be determined with great accuracy from a load test (as will be shown later) even when the exact value of k_2 is not known. But since a knowledge of k_2 is necessary for the calculation of the rotor copper losses under load as well as at no load and, indirectly, for the determination of the core losses from the no load test, it is obvious that the investigation just mentioned should be largely concerned with indicating means for determining or estimating k_2 with a reasonable degree of accuracy.

It is the purpose of this discussion to propose certain methods that could be applied in making such an investigation. The equations that are to be used in their descriptions are essentially the same as those given by Veinott; however, they appear in a slightly different and somewhat simplified form because they contain, instead of the absolute values of the resistances r_1 and r_2 and the reactances x_1 and x_2, the resistance coefficients ρ_1 and ρ_2 and the leakage factors τ_1 and τ_2 which are defined simply by

$$\rho_1 = \frac{i_m}{E} r_1 \qquad \rho_2 = \frac{i_m}{E} r_2$$

$$\tau_1 = \frac{i_m}{E} x_1 \qquad \tau_2 = \frac{i_m}{E} x_2$$

the meaning of E and i_m being the same as in Veinott's paper. Furthermore, it will be assumed that the rotor resistance and reactance have different values for the positive and the negative sequence currents, to be distinguished by the subscripts p and n, respectively. If then, in line herewith, the quantities

$$v_p = \frac{\rho_{2p}}{S} \qquad v_n = \frac{\rho_{2n}}{2-S}$$

$$u_p = (1+\tau_{2p})^2 + v_p^2 \qquad u_n = (1+\tau_{2n})^2 + v_n^2$$

are introduced for the sake of brevity, the torque, line current, power input, power factor, and stator and rotor copper losses at any value of the slip can be expressed in terms of these auxiliary quantities. When the motor runs under ordinary operating conditions $\rho_{2p} = \rho_2$, $\rho_{2n} = k_2\rho_2$, $\tau_{2p} = \tau_2$, and $\tau_{2n} = c_2\tau_2$; with the rotor locked $\rho_{2p} = \rho_{2n} = k_1\rho_2$ and $\tau_{2p} = \tau_{2n} = c_1\tau_2$ (c_1 and c_2 being coefficients smaller than unity).

At any value of the slip s, the running impedance of the motor, with the real component

$$\left.\begin{aligned} &P + r_1 = \frac{E\cos\varphi}{I} \\ &\text{and the reactive component} \\ &Q = \frac{E\sin\varphi}{I} \end{aligned}\right\} \quad (1)$$

is found to be determined by the 2 equations

$$P = \frac{E}{2\,i_m}\left(\frac{v_p}{u_p} + \frac{v_n}{u_n}\right)$$

$$Q = \frac{E}{2\,i_m}\left\{2(1+\tau_1) - \left(\frac{1+\tau_{2p}}{u_p} + \frac{1+\tau_{2n}}{u_n}\right)\right\} \quad (2)$$

It is found further that the expression for the torque contains the factor $(v_p/u_p - v_n/u_n)$, so that the torque becomes zero when this factor vanishes. This happens in the

first place when s has the value $s_0 = {}^1/_2\, k_2 \left(\frac{\rho_2}{1 + c_2\tau_2}\right)^2$, (no-load running) and in the second place when $s = 1$ (rotor locked).

In the no load test, s having the value just stated, Q is found to be equal to

$$Q_0 = \frac{E}{2\,i_m}\,\frac{1 + 2\,(\tau)_{c2}}{1 + c_2\tau_2}$$

in which $(\tau)_{c2} = \tau_1 + (1 + \tau_1)\,c_2\tau_2$

and, since approximately $\sin\varphi_0 = 1$, the measured no load current has the value:

$$I_0 = 2\,\frac{1 + c_2\tau_2}{1 + 2\,(\tau)_{c2}}\,i_m \qquad (3)$$

In the locked test, at normal line frequency, the locked impedance ($s = 1$) is found to be determined by

$$P_1 = \frac{E}{i_m}\,\frac{k_1\rho_2}{(1 + c_1\tau_2)^2 + (k_1\rho_2)^2}$$

$$Q_1 = \frac{E}{i_m}\left[(1 + \tau_1) - \frac{1 + c_1\tau_2}{(1 + c_1\tau_2)^2 + (k_1\rho_2)^2}\right]$$

However, it is proposed herewith to make first a locked test at twice line frequency; if thereupon the locked data obtained at normal current are proportionally reduced to twice line voltage, the locked impedance is found to be determined by

$$P_1' = \frac{2E}{i_m}\,\frac{k_2\rho_2/2}{(1 + c_2\tau_2)^2 + (k_2\rho_2/2)^2}$$

$$Q_1' = \frac{2E}{i_m}\left[(1+\tau_1) - \frac{1 + c_2\tau_2}{(1+c_2\tau_2)^2+(k_2\rho_2/2)^2}\right]$$

so that

$$k_2\frac{\rho_2}{2} = \frac{{}^1/_2(1 + c_2\tau_2)P_1'}{2\,\frac{1 + (\tau)_{c2}}{1 + 2\,(\tau)_{c2}}\,\frac{E}{I_0} - {}^1/_2\,Q_1'} \qquad (4)$$

$$\frac{1}{1 + 2\,(\tau)_{c2}} = \frac{I_0}{E}\sqrt{\left[\left(\frac{E}{I_0} - {}^1/_2\,Q_1'\right)^2 + {}^1/_4\,P_1'^2\right]} \qquad (5)$$

The values of $k_2\rho_2$, τ_1, and $c_2\tau_2$ can now be computed from equations 3, 4, and 5, if it is assumed, for instance, that $c_2\tau_2 = \tau_1$; in addition, i_m follows from equation 3. Thereupon $k_1\rho_2$ and $c_1\tau_2$ can be calculated from the data of the locked test at normal line frequency. On the basis of these 2 locked tests (eventually a third test at half line frequency could be made in addition), a fairly close estimate of the values of ρ_2 and τ_2 can be made, and k_2 and c_2 can be calculated.

If now the data (current, power input, slip, and stator resistance) of a full load test are available, the values of P and Q following from these test data can be immediately computed by means of equation 1. The procedure of determining ρ_2 from this full load test is then as follows: First P is calculated by means of the first equation of equations 2 for a few adopted values of ρ_2, suitably chosen, and for the value of k_2 just found; thereupon these results are plotted in the form of a curve representing the calculated value of P as a function of ρ_2, a curve on which the test value of P will then determine the actual value of ρ_2. Substitution of this value of ρ_2 in the second equation of equations 2 then gives a value of Q which must check within reasonable limits with the test value of Q. Furthermore, the value of ρ_2 just obtained should be compared with the one determined from the locked tests.

The rotor copper loss at any operating point is then equal to

$$2\,i_m E\,\frac{\left(\frac{1}{u_p} + \frac{k_2}{u_n}\right)\rho_2}{\left\{2\rho_1 + \frac{v_p}{u_p} + \frac{v_n}{u_n}\right\}^2 + \left\{2(1 + \tau_1) - (1 + \tau_2)\frac{1}{u_p} - (1 + c_2\tau_2)\frac{1}{u_n}\right\}^2}$$

in which

$$v_p = \frac{\rho_2}{S} \qquad v_n = \frac{k_2\rho_2}{2 - S}$$

$$u_p = (1 + \tau_2)^2 + v_p^2 \quad u_n = (1+c_2\tau_2)^2+v_n^2$$

P. H. Trickey (Diehl Manufacturing Co., Elizabethport, N. J.): I have found the author's method invaluable in locating troubles in regular quantity production of fractional horsepower motors. In fact, in the company with which the writer is associated, standard laboratory procedure on these ratings is based on this method. I am listing below the itemized procedure of the standard analysis test. This test provides the engineer with all the information test is usually increased to include a brake test, temperature run, and a more complete no load saturation. Occasionally it is necessary to take speed-torque curves.

Table I of this discussion shows the arrangement of the test data sheet, which

Table I

			1	2	3
1	LOCKED VOLTS	Em		*	
2	LOCKED AMPS	Im		*	
3	LOCKED WATTS	Wm		*	
4	TOTAL RES. R = W/Im²	Rm			
5	PRI. RES. AFTER LOCKED READING			*	
6	(4) - (5)				
7	IMPEDANCE Z = E/I	Zm			
8	SH. CKT. REACTANCE X = √(Z² - R²)	Xm			
9	NO LOAD VOLTS	Eo		*	
10	(45) × (35) × (39)				
11	INDUCED VOLTS AT FL. (9) - (10) [illegible]	E'		*	
12	MAG AMPS @ E' VOLTS	Io'		*	
13	Xo = 2E'/Io' - X	Xo			
14	Kr = (Xo - X)/Xo	Kr			
15	r2 COLD (6)/Kr) × (17)/(5)	r2			
16	.5 r2 Kr				
17	r1 COLD @ 25°C	r1		*	
18	ro COLD = (16) + (17)	ro			
19	PRIM. RES. AFTER RNG. SAT.			*	
20	ro HOT = ro × (19)/(17)				
21	NO LOAD WATTS AT E' VOLTS	W'o		*	
22	I²R @ E' VOLTS = Io'² ro				
23	CORELOSS + FRICTION = (21) - (22)				
24	FRICTION (30)				
25	CORELOSS AT F.L. = (23) - (24)	Fe			
26	VOLTS @ MIN. AMPS. INPUT	Ef		*	
27	AMPS " " " "	If		*	
28	WATTS " " " "	Wf		*	
29	MIN. CU. LOSS = If² ro				
30	FRICTION = (28) - (29)				
31					
32	NO LOAD WATTS AT VOLTS			*	
33	" " AMPS " "			*	
34	FULL LOAD WATTS AT "			*	
35	" " AMPS " "			*	
36	" " RPM " "			*	
37	" " TORQUE " "			*	
38	" " EFF " "				
39	" " PF " "				
40	" " APP. EFF. " "				
41	MAX. TORQUE " "			*	
42	LOCKED TORQUE " "			*	
43	PULL-UP TORQUE " "			*	
44					
45	PRIM. RES. AFTER FULL LOAD READING			*	
46					
47	STG WDG. RES. @ 25°C			*	
48	* TERMS TO BE FILLED IN BY TESTER				

necessary to obtain the motor constants and separate the losses. In cases of excessive losses or low torques, it is very helpful in locating the defect.

For sample motors of new designs, the facilitates the calculation of the constants from the actual test readings. The specification for motor analysis test are:

1. Cold resistance of all windings
2. Cold "locked saturation" on main winding only. Apply full voltage, read volts, watts, and amperes input; take primary resistance immediately after test. Take readings as quickly as possible as test should be made with motor as nearly at room temperature as possible
3. "No load saturation," main winding only. Take on full voltage, 95 per cent voltage, and at voltage which gives minimum amperes. Read volts, watts, and amperes. Take primary resistance after test. Motor should be at full load temperature
4. Full load reading, motor at full load temperature, read volts, watts, amperes, revolutions per minute, and torque. Take primary resistance after test
5. Maximum torque
6. Locked rotor torque
7. Pull-up torque
8. Locked rotor line amperes (motor at full load temperature)

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In this paper a method has been outlined which makes it possible to analyze stray load losses in single phase induction motors by means of the input-output test together with no load and other tests made for the purpose of determining certain factors. Since the question of stray load losses in single phase induction motors has not received much attention in the past, further use of this method for this purpose is very desirable.

In the paper 2 examples are given, one a $^1/_6$ horsepower and the other a $^1/_4$ horsepower motor, and in both examples the results indicate slightly negative stray load losses. It is further stated that similar conditions have been found in other cases. The author gives 3 reasons for this condition:

1. The relatively small difference between the no load and full load current in single phase motors. (This undoubtedly tends to minimize the load losses.)
2. The necessity for determining the secondary resistance by the locked rotor test. (Under such test conditions there may be certain eddy current losses in the rotor that are not present under load conditions. This issue could be cleared further by making locked-rotor short-circuit tests over a wide range of frequencies. This would permit the determination of the effective rotor resistance for any of the slip frequencies. If for a single phase motor the test is carried up to double frequency, it even will permit the determination of the losses caused in the rotor by the double-frequency exciting current. It is surprising that locked rotor tests at varying frequencies have not been applied to a greater extent to determine the effective rotor resistance at various frequencies; particularly with the deep bar and double-deck rotor windings such tests should give valuable information for either single phase or polyphase motors.
3. The greater difficulty encountered in determining losses in single phase motors. (This is a valid reason for reduced accuracy in results, but it of course does not alter the facts with regard to load losses.)

In spite of the reasons given by Veinott, I believe that appreciable load losses can be present in single phase induction motors and that they can be determined with reasonable accuracy by his method. I believe that in any induction motor except in the larger sizes, the changing densities in the air gap region are responsible for a large part of the stray load losses, especially where the leakage fluxes are likely to saturate the tooth tips and bridges of partially or entirely closed slots. When this is so, stray load losses should be expected in single phase as well as in polyphase motors, although they may be lower in single phase motors because of the first reason given. Additional investigations along this line therefore seem desirable, and it would be particularly interesting if certain polyphase motors having appreciable load losses could be operated on single phase and tested and analyzed by Veinott's method. It is quite possible that with the small motors analyzed in the paper, the saturation of the core iron in the air gap region is low both at no load and at full load, which would tend to keep the load losses low.

C. G. Veinott: R. E. Hellmund is undoubtedly correct in his belief that in general, stray load losses do exist in single phase machines. In my own experiences with fractional horsepower motors, I have found little or no positive evidence to indicate that these losses are sufficiently large to be of practical importance. Hellmund suggests that it would be of interest to select a certain polyphase motor, known to have appreciable load losses, and to operate it on single phase segregating the losses by the means given in the paper, to see if these same load losses were found on single phase operation. It is sincerely to be hoped that this suggestion may be carried out. If one line of a 2 phase motor is opened while the motor is running at no load, the stator current in the excited phase immediately jumps to nearly twice its previous value; part of the stray load loss then would be counted in as a part of the no load core loss, according to present definitions of stray load loss and core loss, and would no longer be called stray load loss.

As Hellmund suggests, both of the motors in the paper were operated at low inductions and the ampere-conductors per slot were low, of the order of 50 or 60.

I am in hearty accord with P. H. Trickey's analysis sheet and happy that he finds the methods of this paper useful. Trickey takes X equal to Q, that is, he assumes that the leakage reactance is equal to the quadrature component of the locked impedance, an assumption which, as stated in the paper, is sufficiently accurate for all practical purposes except when the rotor resistance is very high, such as it is in the case when brass bars or brass rings or both are used. Trickey records sufficient information that at any later time the losses in the motor may be segregated by the methods outlined.

A. Van Niekerk's discussion concerns itself with that portion of the paper devoted to the determination of the constants. The exact value of X is of little importance when segregating losses. More important is r_2 to the determination of which Van Niekerk devotes practically his entire discussion. The principal question raised by him is whether or not it is sufficiently accurate to determine the rotor resistance from a locked reading or must it be determined from a load test. Van Niekerk's method for determining r_2 from a load test, it must be admitted, is considerably more involved and cumbersome than the method given in the paper which is based on a locked test. I, too, once had the idea that r_2 had to be determined from load readings and accordingly worked out a "cut and try" method which I abandoned because it was too cumbersome and the gain in accuracy was decidedly not worth the extra effort involved. Possibly, when the determination of r_2 in itself is required to a high degree of accuracy, Van Niekerk's method should be considered seriously as an alternative to the method given in the paper. In any method of test or analysis of a routine nature, or any schedule of calculation which is often performed, such as the segregation of losses, convenience is of prime importance and should not be sacrificed for only a marginal gain in accuracy. That it is not important to determine r_2 with hairsplitting accuracy in order to check efficiency by losses was unfortunately demonstrated to me in a striking and impressive manner. A large number of motors had been analyzed and the brake test efficiency checked by efficiency by losses using the methods given in this paper. It was then discovered that r_2 had been incorrectly determined from test and all the values in this line of motors were from 5 to 20 per cent too low. Strangely enough, however, the "efficiency by losses" consistently checked the efficiency "by brake test" in all cases. Knowing that these values of r_2 were all wrong, I was somewhat surprised, to say the least, and decided to investigate the point. A number of representative motors were selected, the constants were recomputed and the losses were figured. The remarkable thing was that in most cases, the "efficiency by losses" did not come out more than a point or so different from the previous values. What actually happened, when r_2 was too low, was that the core loss figured too high (because the no load rotor copper losses were too low) and the rotor copper loss under load came too low and these errors practically canceled one another. Thus, it was effectively demonstrated that great accuracy was not necessary in the determination of r_2 since the gain in accuracy of the losses determination is not commensurate with the extra effort.

Perhaps in large machines, it would be desirable to take locked readings at different frequencies as suggested by Hellmund. Such a method would apparently be simpler than Van Niekerk's.

Van Niekerk states that "if, in the case of the $^1/_6$-horsepower 6-pole 60-cycle motor, the stator input is figured for $s = 0.033$, it is found to amount to about 80 per cent of the input measured during the brake test, indicating that the computed full load slip will be roughly 25 per cent higher than the measured value." An interesting comparison is afforded in table I.

This comparison leads me to believe that the discrepancy pointed out by Van Niekerk is due to an error in measuring the slip which was taken by tachometer and not stroboscopically. I believe the slip of the motor probably would have been about

Table I

	Calculated Values From Fundamental Constants		Brake Test Values
Slip s	0.0333	0.043	0.0333
Watts Input	167	201	205
Amps Input	2.97	3.14	3.17
Rotor Copper Loss	22.1	26.1	28.6 or 26.0 (Computed)
Efficiency	56.2	59.2	60.6

0.043 instead of 0.0333 had it been measured stroboscopically; this represents an error of only 1 per cent in reading the tachometer. Again, a striking difference between single phase and polyphase motors comes to light; if the measured slip of a polyphase motor were 20 per cent too low, the rotor copper loss would also be 20 per cent too low. Reference to figure 3, however, shows that when $r_2/X_0 = 0.06$, as in the chosen example, the rotor copper loss is practically the same for $s = 0.043$ as it is for $s = 0.0333$. Thus, in the particular instance, an exact measurement of the slip is not important, although it is in many cases.

It is to be hoped that the methods given in this paper will be tried and their merits determined by practical use. After all, the worth of any new method of analysis is determined better by practical use than by a mere academic discussion of it. At least 3 different electrical manufacturing companies are making practical use of these methods and indications are that more may do so.

Flashing of Railway Motors Caused by Brush Jumping

Discussion and author's closure of a paper by R. E. Hellmund published in the November 1935 issue, pages 1178–85, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 29, 1936.

C. G. Veinott (Westinghouse Elec. and Mfg. Co., Springfield, Mass.): This paper presents a new and wholesome approach to the irksome problem of flashing of railway motors caused by brush jumping. Designers are sometimes prone to take the ratio of armature ampere turns to field ampere turns as a highly significant ratio and one upon which they judge many characteristics of the motor, such as commutation and susceptibility to flashing. The paper shows why, in some cases, this ratio is significant and why in other cases it has but little significance. The approach is simple, direct, straightforward, and easy to understand, and consequently more useful to a designer than long sets of equations and complicated mathematics.

In figure 12, curve B, the author shows that the time of brush lifting to cause a flash is 0.014 seconds. This would appear to be about the length of time necessary for a bar to travel from one brush arm to the other. The speed of the motor is not given, but if it is assumed to have been 1,000 rpm, which seems a reasonable assumption, and if further it is assumed that it was a 4 pole

motor, 0.015 second would be required for $1/4$ of a revolution, or 0.015 second required for a commutator bar to traverse from one brush arm to the next. This would lead me to believe that in this case probably the arc did strike to other parts of the commutator, forming other arcs in parallel, and that the longer arcs were extinguished. I would like to ask the author if he agrees with this viewpoint or if he found any other evidence to indicate that the arc did restrike to other bars on the commutator.

F. B. Powers (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Recent tests on a machine equipped with 4 brush arms and 1 brush per arm indicate flashing at very low speeds, when such speeds are accompanied by high currents. While we do not normally consider the lower speeds to be in the critical zone, the particular machine under test happened to be rather sensitive in the high current range.

The fact that flashing occurred under these conditions indicates that the transfer of large currents from one brush arm to another under poor brush riding conditions is accompanied by a voltage sufficient to maintain an arc once established and to cause flashover. It is interesting to note that under the same test conditions at higher machine speeds and lower current, flashing did not occur.

W. A. Brecht (nonmember; Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The brush lifting device used in commutator flashing tests by the writer and referred to in the paper is shown schematically in figure 1 of this discussion. It consisted of a lever pivoted on a knife edge, with one arm wired to the brush. From the other end a wire was suspended with a compression spring at its lower end, as shown. Threaded on the wire was a cylindrical steel weight which could be dropped from any height onto the spring.

With the weight of the brush and the spring constant of the brushholder spring known, differential equations of the motion of the brush were written and solved, resulting in the equation

$$h = \frac{p^2}{2kw}\left(3.02\frac{kt^2}{w} + 1\right) \qquad (1)$$

in which

w = weight of falling body = 0.2 pound
k = spring constant (22.4 pounds per inch used)
h = inches of fall
p = pounds brush pressure
t = time in seconds that brush is lifted

This was simplified further into

$$\frac{h}{p^2} = 0.112\,(3370\,t^2 + 1) \qquad (2)$$

in which the only unknowns are the height of fall of the weight, the brush pressure on the commutator, and the time of the brush lift. Equation 2 is plotted in figure 1 of this discussion.

After the device was assembled the theory was checked by a calibration made with the aid of an oscillograph. The calibrated points are shown on the curve to agree very closely with the calculations.

The device was used in 2 ways: first, to ascertain the effect of varying the time of brush lift; and second, to find the voltage at which flashing occurred using a fixed time of lift.

N. W. Storer (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author has given a very clear analysis of one phase of the problem of flashing in railway motors. Undoubtedly, a great deal of flashing has been caused in the past by brush jumping. This may have been due to rough track, or

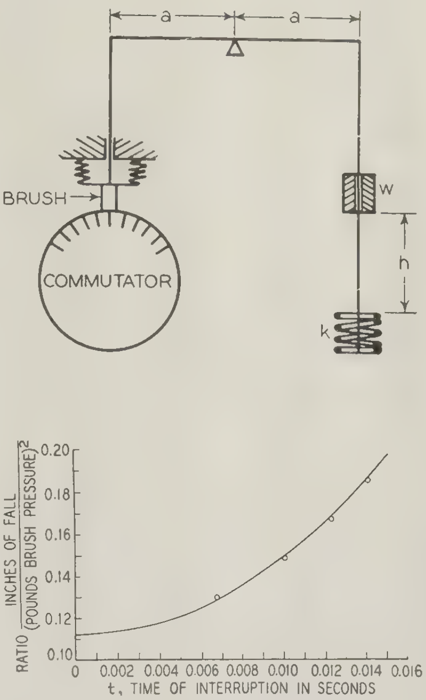


Fig. 1. Diagram of brush lifting device, and comparison of calculations and calibrated points

Calibrated points indicated by ⊙

a track with too rigid a foundation; to a commutator with high bars or a commutator that did not stay cylindrical or tight; to brushes that chatter or had too light a spring tension; or to worn armature bearings that permitted the entire armature to "jump" with respect to the brushes.

The demand for small light weight motors has led to armature speeds that were undreamed of a few years ago, speeds that would have been impossible with the old methods of design and construction.

Many changes have been necessary. More attention is paid to electrical design, especially to securing good compensation at all speeds and loads; commutators have an improved construction and are carefully seasoned at high temperature and high speed before the armature is assembled; the finished armature is given a perfect running balance; the motor has roller bearings which maintain correct gear center distances and prevent loose bearings; the motor is entirely spring borne; and there is a brush holder for every pole.

In addition to the foregoing features, the modern motor has class *B* insulation and a very efficient system of self-ventilation, both of which have helped greatly to reduce the weight of street railway motors to the neighborhood of 10 pounds per horsepower with very stable performance.

R. E. Hellmund: I appreciate W. A. Brecht's discussion because it supplements my paper and shows in detail the test method used in connection with the curves of figure 12 of the paper. It also gives some evidence of the accuracy of these tests. This, together with the point raised by C. G. Veinott in his discussion, indicates that for certain test conditions in figure 12, particularly those for the higher loads of the series-connected motor as well as for the points with separate excitation at 60 amperes, the basic theory given in the paper is not sufficient to explain the results fully. It is evident that some of the secondary phenomena discussed in the paper, especially the possibility of the shifting of the hot-cathode spot on the commutator, has to be assumed under some of these test conditions. This was believed to be the case when the paper was written, as stated in a footnote on page 1185; however, at that time no supporting experimental evidence was available. Some additional tests have since been made which show that at least with some of the heavier currents the shifting of the hot-cathode spot on the commutator toward the brush takes place at times, but it was also found that this shifting does not seem to occur regularly and therefore cannot be depended upon in practice. This then means that in order to work safely, this shifting should not be relied upon and that the basic procedure suggested in the paper is after all the safest method to follow in calculations.

The practical case covered in the discussion by F. B. Powers is of interest in that it brings out that even with a brush for each pole, flashing from brush jumping can occur. As pointed out by him and also in my paper, such conditions are influenced largely by the inductive voltage induced in the coil between the brushes of the same polarity when one of these brushes leaves the commutator. This voltage naturally is highest at heavier currents, as pointed out by Powers.

I fully concur with N. W. Storer's remarks to the effect that great improvements have been made in up-to-date motors in a number of respects which favor the elimination of flashing caused by brush jumping. Without this, the appreciably increased motor speeds now in use would not have been possible, and in fact the theory given in the paper plainly indicates that intolerable conditions would exist in modern motors if such improvements had not been made. However, even in these improved motors it is still necessary to properly proportion the electromagnetic design features of the motor so as to reduce as much as possible flashing possibilities either from brush jumping or power interruptions. A complete study of this requires in addition to the method given in the paper, basic data on the arc characteristics as applying to commutator conditions. Investigations along this line have now been made and will be given in some future publication. These tests, together with the method of attack of the present paper will make it possible to make comparative studies of the electro-

magnetic features of motor designs under the assumption that the mechanical conditions for brush jumping are the same in the designs being compared.

Discharge Currents in Distribution Arresters

Discussion and authors' closure of a paper by K. B. McEachron and W. A. McMorris published in the December 1935 issue, pages 1395–99, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Md.): The data reported by the authors have been needed. It is hoped that other companies will co-operate in the collection of this data so that in the future a sufficiently large amount of this information will be available for a more accurate consideration of probability factors. In studying the data obtained to date it is surprising to find the low surge current experienced. In the past, many troubles with lightning arresters on distribution systems have been attributed to surge currents in excess of those which the arrester or the gap were capable of carrying. These troubles supposedly were solved by increasing the discharge current carrying capacity of the device. However, these data indicate that the maximum current for which the latest devices are designed is many times the maximum encountered in service; yet these devices are failing, and in most cases without showing indications of direct strokes. In fact, from the data presented, the probability of surges over 10,000 amperes is so small that high surge currents cannot explain past troubles.

H. M. Towne (General Electric Co., Pittsfield, Mass.): The data presented by the authors on the magnitude of lightning discharge currents through distribution arresters can be used in combination with available data on impulse current-time characteristics of fuse links for determining the possibility of primary fuses being blown by lightning currents where the fuses are located on the line side of the arrester at distribution transformer installations. Obviously, if the primary fuse is connected in the line side, or ahead of the lightning arrester, any lightning discharge currents must pass through the fuse to the arrester discharge circuit to earth. The possibility of the fuse being blown by the lightning discharge current depends upon the current rating of the fuse element, its current-time characteristics, and the amplitude and duration of the lightning discharge current.

Figure 1 of this discussion shows the impulse current-time characteristics of fuse links as determined by Duvoisin and Brownlee (see "Impulse Characteristics of Fuse Links," E. M. Duvoisin and L. Brownlee, *G. E. Review*, v. 35, May 1932, p. 260–66). The highest safe impulse current of, say, 20 microseconds duration, that could be passed through a 3 ampere fuse element is seen to be about 2,500 amperes. A fuse rated at 5 amperes will withstand an impulse current of about 4,200 amperes and a fuse rated at 10 amperes will withstand an impulse of about 10,000 amperes, of the same duration. For impulses with shorter time elements, the fuses will withstand higher currents, whereas longer duration of impulse currents would cause fuse blowing at lower current amplitudes. Although over $^9/_{10}$ of all discharge currents measured by the authors are below 5,000 amperes, which probably would not blow fuses of 5 ampere rating or greater, it appears that the relationships between the authors' expectancy curves for higher discharge currents and the impulse characteristics of fuses should be considered in applications where the fuses are located on the line side of the arrester discharge circuit to earth. Although there are no data on the actual duration of the lightning discharge currents measured by the authors, it may be that the less frequent and higher amplitudes of discharge currents of from 10,000 to 15,000 amperes involve relatively short time durations. Data on the actual duration of discharges in service, as well as on the number of multiple or rapidly recurring discharges, will be necessary before any exacting correlation can be established for the probability of fuses being blown by the passage of lightning currents. Available data, however, permit a fair approach to this problem.

L. R. Ludwig and **A. M. Opsahl** (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): The paper by K. B. McEachron and W. A. McMorris contains considerable valuable information on measured surge currents through distribution arresters. According to the authors, the maximum currents recorded are so close to the limits of accuracy of the measuring apparatus that the writers would like to inquire whether it is possible that higher values may have occurred, but have not been recorded properly. According to figures 3, 4, and 5 of the paper, 2 per cent of the surges have a magnitude of 15,000 amperes or more. Since each arrester must be expected to operate on surge 1 or 2 times per year (see "Lightning Investigations on a Distribution System," Herman Halperin and E. H. Grosser, Elec. Engg., v. 55, Jan. 1936, p. 63–70) the number of surges of a magnitude larger than 15,000 amperes, on a system containing 10,000 transformers, would be from 200 to 400 per year. This frequency of occurrence is so large that distribution arresters must be made adequate for surge currents of this order of magnitude.

It is interesting to note from L. G. Smith's paper ("Distribution Transformer Lightning Protection Practices," Elec. Engg., v. 55, Jan. 1936, p. 47–53) that the arrester failures average about 1.5 per cent, and to compare this figure with the results from this paper that about 2 per cent of the surges are of a magnitude of 15,000 amperes or greater. Assuming that the arrester failures are due mostly to surge currents, these facts indicate that arresters now in the field have a surge current capacity just a little more than 15,000 amperes, perhaps 20,000 amperes. The arrester failure rate of 1.5 per cent certainly is too high to be desirable, and in order to reduce it considerably, arresters should be built with a surge current capacity of at least 50,000 amperes. Such capacities are available in modern distribution arresters, and if data were available on the performance of this modern apparatus only, much lower arrester failure rates would be indicated.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): Data such as those obtained by K. B. McEachron and W. A. McMorris should be of value, not only in learning more about the characteristics of lightning surges on distribution systems, but also in arrester design involving the requisite surge current capacity to incorporate in arresters for various service conditions. Experience indicates that the present distribution type arrester probably has, at least for certain conditions, about the proper surge capacity. Additional field measurements of surge currents and their effect on arresters may indicate, however, the desirability of some changes in arrester design for some conditions.

C. M. Foust (General Electric Co., Schenectady, N. Y.): In connection with the use of the surge crest ammeter in the investigation outlined by K. B. McEachron and W. A. McMorris, the writer would like to make it clear that the use of the galvanometer is entirely supplementary and adds

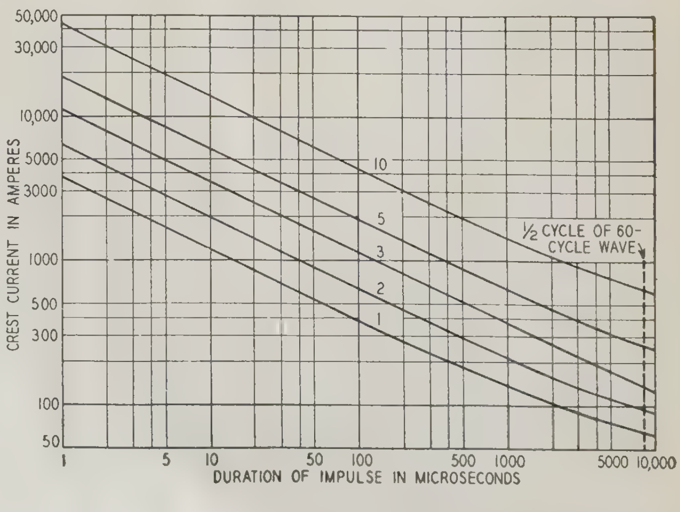


Fig. 1. Impulse current-time characteristics of fuse links

Number on each curve indicates the fuse rating in amperes

to the normal 10 per cent accuracy only in occasional cases such as pointed out. The essential elements required for measurements at one station are 2 magnetic links, a supporting bracket, a surge crest ammeter, and a calibration curve. Auxiliaries such as magnetic link keepers, magnetization indicators and magnetizing and demagnetization coils provide additional facilities where required. The first 3 auxiliaries provide for link protection, magnetization detection, and calibration checking. The demagnetizing coil permits repeated use of the links.

It may be of interest here to summarize briefly the extent of the application of the surge crest ammeter. More than 5,000 measuring stations were in operation during 1935. Up to and including 1935, more than 1,500 records of crest values of lightning surges have been recorded. On transmission line tower structures, about 900 records involving 365 towers and about 300 lightning strokes have been obtained. Tower currents range up to 132,000 amperes and total stroke currents to 220,000 amperes. More than 24 records of lightning currents in tower top lightning rods have given an upper limit of 25,000 amperes. In counterpoise wires the maximum current found in a total of 209 records was 17,000 amperes. A record of 162,000 amperes has been obtained in a radio mast. These records have been used to determine the distribution of current between tower legs, the effectiveness of radial and parallel counterpoise, as well as to give an indication of the location of the stroke.

K. B. McEachron and **W. A. McMorris:** C. M. Foust has called attention to the fact that the surge crest ammeter would ordinarily be used instead of a ballistic galvanometer in making measurements on magnetic links. As pointed out in the paper, current readings were made on links that were magnetized beyond the normal range over which average calibration curves can be depended upon to give accurate results, unless links are selected carefully for uniformity. By taking advantage of the laboratory available facilities and making individual calibration tests on the strongly magnetized links, the range in which accurate measurements could be made was extended considerably.

The use of a galvanometer instead of a surge crest ammeter ordinarily would not be necessary, and in fact would not be practical where field measurements are to be made on the links.

L. R Ludwig and A. M. Opsahl have asked whether there is a possibility that discharges of greater magnitude than those reported might have occurred without being properly recorded, because of limitations of the recording instruments. The writers do not feel that the highest currents recorded are the highest that a lightning arrester may ever be required to handle. However, for the higher currents recorded, individual calibration tests were made on the links involved, over a range of magnetization extending both above and below the values found in the field. This indicates that the links were capable of recording higher current discharges if they had occurred.

In this investigation, 3 discharges of 15,000 amperes or more were recorded in 1,225 arrester-years of service, which corresponds to 25 such discharges per year per 10,000 arresters. This actual measurement in the field may be compared with Ludwig and Opsahl's estimate of 200 to 400 such discharges per year per 10,000 transformers.

Judging from the paper by Halperin and Grosser ("Lightning Investigations on a Distribution System," Herman Halperin and E. H. Grosser, Elec. Engg., v. 55, Jan. 1936, p. 63–70) and from L. G. Smith's experience as given in his discussion of this paper, it does not appear justifiable to assume that arrester failures can be predicted merely on the basis of maximum discharge current capacity. In this investigation 8 arrester failures were reported at locations where magnetic links were installed. In 4 cases the discharge current recorded was 500 amperes or less. In the remaining 4 cases, the currents recorded were between 500 and 5,000 amperes, although one of these arresters had passed a current of 15,000 amperes a few months before.

That the percentage of the records indicating currents of 15,000 amperes or more is so nearly equal to the percentage of arresters that have failed, appears to be merely a coincidence. The 2 percentages are not even expressed in terms of the same base. So far this investigation has shown little correlation between arrester failures and the magnitude of discharge current.

As suggested by H. M. Towne, the data obtained in this investigation make possible the application of data published by Duvoisin and Brownlee on the impulse current-time characteristics of fuse links. This should help to clarify the problem as to whether or not primary fuses should be installed on the line side of arresters.

With reference to the discussion of Halperin and Smith, this investigation is to be continued to obtain additional data on arrester discharge currents, and on the performance of arresters when subjected to actual lightning discharges of known magnitude.

Lightning Arrester Economics

Discussion and authors' closure of a paper by Philip Sporn and I. W. Gross published in the January 1936 issue, pages 84–93, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 30, 1936.

H. M. Towne (General Electric Co., Pittsfield, Mass.): The authors have presented a valuable and most interesting treatise of lightning arrester economics. The retrospection of earlier operating opinions toward the value of arresters and reasons motivating their applications or omissions, together with the modern economic dictates and conclusions drawn by the authors, bear testimony to the evolution and advances in knowledge of arrester design and application engineering.

The authors show in table II of the paper that experience with 2,771 unprotected distribution transformers over a 2 year period resulted in 1,068 total lightning troubles and 927 fuses blown and 85 transformers burned out. The yearly average is 38.5 per cent for total troubles, 33.4 per cent for blown fuses and 3.1 per cent for transformer burnouts. The figures of 29.4 per cent and 29.8 per cent given in table II of the paper for total troubles and fuses blown respectively, appear to be in error in the summarizing of yearly averages for the 1934 and 1935 tabulated data.

It is reasonable that most blown fuses and transformer burnouts represent lightning conditions where surge amplitudes exceeded the lightning flashover or breakdown strength of the transformers. Then adding the figures 33.4 per cent for fuse blowing and 3.1 per cent for transformer burnouts, it appears that lightning surges exceed the transformer insulation level at the rate of about 36 per cent. In other words, about 1 transformer of every 3 installed would be subject to lightning voltages exceeding the transformer insulation strength each year.

It is interesting to note the agreement between this apparent rate and the rate indicated by the McEachron and McMorris field measurements (see "Discharge Currents in Distribution Arresters," K. B. McEachron and W. A. Morris. Elec. Engg., v. 54, Dec. 1935, p. 1395–99) of surge currents through arresters. The field measurements involved 1,225 installations under test, for which 411 records of surge currents were obtained. McEachron and McMorris point out that their lower limit of current measurement corresponds to traveling wave amplitudes that would be dangerous to unprotected transformers; hence, the 411 total measured currents of 1,225 total installations indicate that 33.6 per cent, or about 1 of every 3 transformer installations were subjected to lightning voltages exceeding the transformer insulation strength. Although the data by McEachron and McMorris apply to 4 distribution systems quite widely separated geographically, the average conditions for installation susceptibility appear to agree closely with the Sporn and Gross data for Ohio.

Naturally, the conditions in Georgia are more severe than average, and as indicated by the McEachron-McMorris data for the Georgia system alone, there were 231 records of 251 installations indicating that about 92 per cent of the transformers, or nearly every transformer installed would be subjected to lightning voltages exceeding the transformer insulation strength each year. Hence, such high rate of susceptibility in the more severe lightning territories should result in even greater economic justification for protection than computed by Sporn and Gross from data representing more nearly average conditions of lightning prevalence and severity.

The authors have given some interesting figures for unit costs of lightning damage. Data of this character are most important in evaluating the economics of protection. To the writer's knowledge, the only data previously published were those accumulated by the Empire State Gas and Electric Association (see "Transformer Outages Determined by Ground Conditions," R. Phillip Hart. *Elec. World*, v. 98, Sept. 12, 1931, p. 456–58) wherein the average cost of a blown fuse was given as $5.20, and the average cost of a transformer burnout $69.95. It is reasonable to suppose that these costs of lightning damage will vary over quite a range for different utilities compiling the data, depending on territory served and accounting methods for labor,

material and transportation necessary in making repairs and re-establishing service, together with the costs of loss of customer revenue and good will attending the period of service interruption. As pointed out by Sporn and Gross, the extension of distribution systems, and therefore the increasing expense of servicing, is an important item in the economics of complete protection. It would be most valuable if other utilities would compile figures for unit costs of lightning damage as done by the authors. Perhaps the collection of such additional data could be included with the continuation of the excellent survey conducted by L. G. Smith (see "Distribution Transformer Lightning Protection," ELEC. ENGG., v. 55, Jan. 1936, p. 47–53), involving the 38 operating companies contributing other data on distribution transformer lightning protection practices.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): In the light of present knowledge on insulation co-ordination, the authors have directed their efforts to re-examine certain aspects of the economic problem. It must be conceded that in a study of this kind dependable conclusions may be reached only if the technical basis is sound.

Past experience in the form of statistical data, such as given in table II of the paper, for example, is essential, but such detailed records have been obtained only recently. The question may then be asked whether more statistical data for a number of the coming years are not required, if the conclusions deduced by the authors are to be accepted with assurance.

Besides, fundamental knowledge of the impulse characteristics of apparatus and protective equipment is equally essential for dependable economic analysis. An illustrative example on this point would be table VII of the paper. It can hardly be said that the fundamentals have been completely explored; accordingly, all conclusions on the economics of the problem naturally change with new developments.

At the present time, co-ordination methods between apparatus insulation and protective equipment can in general be ascertained by laboratory test, but experience over a reasonable number of years is necessary before conclusions on the efficiency of newly proposed methods can be stated with reasonable certainty.

For these reasons the conclusions in the paper based on 2 years of service seem premature. There is no question, however, that the time is ripe for analysis of the economic problem along the lines the authors have given. From this standpoint their contribution is of a pioneering character.

F. J. Vogel (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): This paper is indeed interesting in marking the progress made in the design of transformers and protective equipment. It is fundamental in the scientific design of any machine, that it be known what stresses the machine will have to withstand, and how to design it to withstand these stresses. In the early days there is no question that a knowledge of both of these factors was lacking, and if service experience was satisfactory it was a matter of luck alone.

The progress that has been made is in 2 directions, the direction of a knowledge of the stresses that will be permitted by arresters or other protective means, and the direction of complete knowledge of the insulation strength of transformers. This knowledge has been obtained recently, and its application is not yet of sufficient duration to obtain completely satisfying statistical data.

It is true that laboratory work alone is not implicitly reliable, and undoubtedly statistical data and field experience have great value. However, they may be very misleading when taken by themselves. An example of this is as follows: The opinion of most engineers some years ago was that the percentage of annual failures was low on large transformers, and that line insulation was generally within certain limits; therefore, transformer insulation was generally above the surge strength level of the line insulation. Nothing could be further from the truth, since in many cases transformer insulation was far below such levels, and yet good operating records were obtained. The writer's own opinion is that the statistics show severe surges on the larger transformers to be relatively rare, but that there may be disconcerting exceptions. For example, the writer knows of one transformer bank that was in service 5 years before a failure occurred, and the strength of which was far below the line insulation strength. In another instance the design had been in line with past design methods, and was in line with many other transformers, but failures occurred almost every year until better protection was afforded. This leads the writer to question the comparison between the service record of table VI, of the paper, between over-insulated transformers and ordinary transformers with arresters. It is possible that severe surges have not actually reached these 18 over-insulated transformers.

Without intending to discredit the installation of really co-ordinated apparatus, and for similar reasons to those discussed in the foregoing paragraph, it is believed that the statistical evidence of 2 years satisfactory service of a particular bank of transformers with arresters possibly is not as convincing as actual tests at the manufacturer's works. Where such installations as described are to be made, the writer believes that the facts should be demonstrated by test, so that a real comparison between the results by test and service experience can be made.

L. G. Smith (Consolidated Gas, Electric Light, and Power Company of Baltimore, Md.): An effort to balance the economics of lightning arrester protection is of considerable interest to the industry. The authors are to be congratulated on making an original step in this direction. The writer's first reaction to the paper was the realization of the general lack of data on operating results that could be used as a base for economic studies of this type. It certainly behooves the industry to follow the thoughts developed in this paper and to make such operating data available.

In the discussion of the application of arresters on distribution systems, apparently the authors used the average rates of transformer burnouts and primary fuses blown as a basis for the curves in figures 1 and 2 of the paper. If such is the case, any economic balance for the use of lightning arresters should be based upon the average cost of transformers instead of the cost of each size of transformer. It is believed that it is not correct to assume average rates of transformer burnouts and primary fuses blown for all sizes of transformers. The following table shows the average rates of these troubles over a 5 year period for 4 sizes of transformers on the system of the company with which the writer is connected:

Size Amperes	Primary Fuses Blown, Per Cent	Transformer Damage, Per Cent
$1^1/_2$	17.3	1.8
5	7.0	0.98
15	2.9	0.72
25	1.9	0.42
Average	9.8	1.15

In this table the transformers damaged include winding failures, but are not limited to this type of failures. However, transformer winding failures should follow very closely the same trend. The above data are based upon transformers protected with lightning arresters using the standard connection. Since the decreasing rate of troubles with increase in size seems to be an inherent characteristic of the transformer, the same trend undoubtedly will be found to exist with other methods of lightning protection, or without any lightning protection.

In the section dealing with medium voltage applications, the statement that the elimination of additional spare equipment will justify lightning protection is questioned, in view of the fact that if spare transformers are meant by the authors, they would also be required for other reasons. On this class of transformers service is also a determining factor, since transformers of this voltage usually supply distribution loads frequently over sizeable areas.

The idea of purchasing lower insulated transformers for use with lightning arresters, which will restrain the voltage to a safe value, is an intriguing one and opens the possibility of saving considerable money to the industy if lightning arresters can be depended upon to function in accordance with their laboratory characteristics. However, it is believed that in applying this principle it is essential to shield adequately the substation and the line wires for a sufficient distance from the substation, so that the magnitude of surges entering will be limited to the impulse level of the transmission lines connected to the substation. In the field of medium and higher voltage transformer protection, the industry is in need of a greater volume of carefully collected data.

T. H. Haines (Edison Electric Illuminating Company of Boston, Mass.): In this paper a table is given in which the Edison Electric Illuminating Company of Boston is represented as installing arresters on transformers no smaller than $7^1/_2$ kva. This was true until 1930 only. Quoting from a paper read

by the writer before the Boston Section of the A.I.E.E., December 13, 1932, "A study of the individual troubles over the years indicated the extreme susceptibility of the small transformers to lightning troubles. For instance, in 1929 the transformers of 5 kva or less constituted 30 per cent of the transformers and contributed 50 per cent of the trouble; in 1930, the 5 kva and smaller, constituted 28.5 per cent of the transformers and had 67 per cent of the trouble. A study of the economics of the situation with these figures in mind resulted in the decision to equip all transformers, regardless of size, with protective equipment."

This decision resulted from the fact that in the earlier days transformer manufacturers followed the odd practice of adjusting the bushing size and internal clearances to the scale of dimensions of the transformer instead of to the operating voltage.

With modern transformers, in which bushings are of equal flashover value regardless of size, these economics may hold, but this company never has re-established the limit here given.

Under the heading "Broad Economic Considerations," protection of service is mentioned as an element to be considered in evaluating lightning arrester justification. Apparently loss of good will due to customer outage has not been included in the economic study. To use it in such a study, it must be evaluated, but it is a thing that no individual seems willing to do, at least for publication. If any reasonable value in money is assigned to the kilovolt-ampere-hour outage or loss of service, the minimum kilovolt-ampere limit for transformer protection worked out in this paper would be reduced considerably.

Robert Treat (General Electric Co., Schenectady, N. Y.): It is indeed gratifying to one who has long advocated the use of lightning arresters, that careful studies clearly have demonstrated their utility to such prominent engineers as the authors of this paper. Their experience and reputation are adequate guarantee against their having been misled by wishful thinking—a suspicion from which one associated with a manufacturer of these devices is sometimes not entirely free.

This subject has one important aspect, treated briefly in the paper, on which the writer wishes to offer further comment.

Much of the existing apparatus to which lightning arresters may be properly applied was built with less than present standard insulation strengths, and these strengths certainly have not increased with age. It is sometimes a problem to select an arrester capable of affording any protection to this old apparatus without incurring the possibility that the arrester itself may be injured by certain conditions of operation to which it is occasionally subjected. This is likely to happen when the arrester is located near a hydroplant that may be subject to runaway and high dynamic voltage on loss of load, especially if the system neutral is not grounded. In such a case, some operators have proceeded on the basis that they must not risk the failure of an arrester, even though the avoidance of that risk dictated the choice of an arrester to which no amount of wishing could successfully ascribe much protective value. The arrester manufacturer occasionally has been somewhat sympathetic with such a viewpoint, because he realized that, regardless of extenuating circumstances, a failure of his arrester might be used to his disadvantage; whereas, if it merely failed to accomplish its purpose, the arrester was much less likely to be blamed.

Fortunately, this attitude on the part of both operators and manufacturers is beginning to pass and to be replaced by a viewpoint more in keeping with that of the authors of this paper.

It is suggested that an approach to the problem of protecting old apparatus from lightning, along the lines suggested in this paper, would reveal many cases in which it would be good business to change present installations. Such an approach might well disclose that the attitude of preventing the failure of the arrester without regard for the protected apparatus is costing real money, much of which could be saved by adopting a policy of improving the protection of apparatus, even though the improved protection entailed the risk of occasional damage to an arrester.

Herman Halperin (Commonwealth Edison Co., (Chicago, Ill.): In connection with the paper by Philip Sporn and I. W. Gross, the writer's studies, including those on the effect of arrester density on the rate of lightning troubles on the distribution system, have indicated that with no arresters the annual rate of transformer failures would be roughly 5 per cent in Chicago as compared to about 0.4 per cent with normal arrester protection and to about 0.2 per cent with interconnection. Following the authors' methods, it is found that for distribution transformers arresters are justified from purely an economical consideration for sizes larger than 15 kva. The method of calculation used by Sporn and Gross assumes a constant rate of lightning troubles regardless of transformer size. Experience has indicated, however, that smaller transformers have a higher failure rate, which would tend to lower the minimum size limitations for economic usage of arresters. With this consideration, their decision to use arresters on the smaller sizes of transformers may be well justified solely on the basis of protection of equipment.

L. R. Ludwig and **A. M. Opsahl** (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): In table II of the paper by Philip Sporn and I. W. Gross, it can be seen that the arrester connected to ground and case, and the gap to neutral, which is a form of 3 point protection or gapped interconnection, has given the best results of any of the combinations tried. This is quite in line with theoretical expectations. The data are somewhat limited, of course, but probably are indicative.

The authors have introduced a possible new trend in coupling an adequate type of lightning arrester closely to its associated transformer, and accepting lower than normal insulation of the transformer with resultant saving in cost. It is, of course, somewhat early to draw definite conclusions as to the desirability of this procedure. Normal operating limits have been cut in order to achieve a cost saving, and although the probability of successful operation looks very good from a theoretical standpoint, time alone can tell whether modern arresters and transformers are adequate to be operated together in this way without additional lightning trouble which might easily offset the saving effected. Certainly arresters have been developed to the point at which a field trial with this type of combination has been warranted, and further results are awaited with interest.

Philip Sporn and **I. W. Gross**: The authors wish to thank H. M. Towne for calling attention to an error in table II of the paper, wherein the yearly average blown fuses should have been 463 instead of 414, and the percentage 33.4 instead of 29.8. Similarly, the total cases of trouble should have been 534 instead of 483, and the percentage 38.5 instead of 29.4. However, if the data for transformers operating with no arresters and cases grounded are included as well as those transformers with cases ungrounded, the blown fuses and total cases of trouble become 27.5 per cent and 31.5 per cent, which are approximately $^1/_5$ below the figures for distribution transformers with cases ungrounded. It is interesting to note the conclusion Towne has reached that 1 distribution transformer in every 3 yearly is subjected to a lightning disturbance sufficient to cause damage to the transformer.

T. H. Haines's present practice in applying arresters to all transformers instead of those no smaller than 7.5 kv, which he states was done until 1930, clearly indicates the necessity for making changes in operating practice as soon as additional information becomes available. As noted in the paper, the authors recently have changed their practice to include lightning arresters on all transformers, but in 1932 they recommended using them only on transformers of 5 kva and above.

The thought of both T. H. Haines and Herman Halperin, that troubles on distribution transformers are lower for the smaller capacities, the authors recognized were at the time the paper was written, but it did not seem to be feasible to incorporate these in the curves. It is true, however, that this is an added factor to be taken into account in arriving at a decision on just how far to go in applying arresters on transformers of various sizes. It should clearly be pointed out that it is practically impossible to devise any group of curves that will apply under all conditions, but as accurate field data become available, they undoubtedly can be used to make the result more specific than a general analysis. In fact, the lightning conditions in different territories will govern to some extent the ultimate choice as to whether arresters are to be used or not.

Several discussers questioned the advisability of using a derated arrester and underinsulated transformer, and expressed the opinion that laboratory tests are more convincing on the ability of the transformer equipped with a lightning arrester attached to withstand lightning voltages in the field than 2 years of operating experience. It might be of interest to point out here that the particular transformer installation referred to had an impulse test in the factory; moreover, it had a factory impulse test with the lightning arrester connected to the transformer, arranged practically the same as in

the field. In fact, in appreciating that this was a trial installation in the development of protection along what appeared to be sound but untried lines, every precaution was taken to see that sufficient tests within reason were made previous to the installation to insure success in the field.

The discussions have stressed the importance of gathering more fundamental data on the performance of transformers and lightning arresters under field conditions and with this the authors thoroughly agree. The table presented by L. G. Smith contributes to this information and should be useful in more accurately determining maintenance costs alone in protecting transformers against lightning for different sizes of transformers.

Smith questions also the possibility of eliminating spare equipment in the medium voltage class if lightning arresters are used and assurance is obtained that lightning troubles will be decreased. This, of course, is a question that each company must decide for itself, but where quite a few similar transformers are used, it apparently would not be economically sound to provide the same number of spare units with a transformer failure rate of say 5 per cent, which might be experienced without the use of lightning arresters, as if the transformer failure rate were only 0.5 per cent. This does not apply in the case of one transformer bank only in which a single transformer unit generally would be provided as a spare.

Measurement of Telephone Noise and Power Wave Shape

Discussion and authors' closure of a paper by J. M. Barstow, P. W. Blye, and H. E. Kent published in the December 1935 issue pages 1307–15, and presented for oral discussion at the communication session of the winter convention, New York, N. Y., January 28, 1936.

J. J. Smith (General Electric Co., Schenectady, N. Y.): The authors point out that the revised TIF weighting curve given in this paper includes the results of a large amount of additional work carried out on this problem since the publication of the paper by H. S. Osborne in 1919. The main differences in the weighting are at the lower and upper frequencies. The curve given by Osborne had a weighting factor of about 9 for 60 cycles per second, and this was too high. The new curve has a weighting factor of 1 for 60 cycles per second, which perhaps is nearer the true relative value of the interference effect at 60 cycles per second. The writer should like to inquire whether the value of 1 as adopted on the present curve correctly represents the interference effect at a frequency of 60 cycles per second, or whether this may still be high because it would be somewhat difficult to develop a network to give its true value, and practical considerations do not require this. The other major change in the curve occurs in the region of from 1,500 to 3,000 cycles per second. Here the average value of the new curve is approximately 3 times that of the old curve. The tests to derive the original curves in Osborne's paper did not cover this region. It is now hoped that with the number of data used in the revision of these curves, no future revisions will be necessary.

The engineers associated with the manufacturers of electrical apparatus have cooperated in obtaining a correlation between the TIF values based on the old and the new weighting curves. As the authors point out, a scale has been chosen to give reasonably good correlation. This will make it easier to change from the old to the new weighting curves and the data obtained with the original TIF meter still will be of value.

In connection with the tests on rectifier noises, it is not clear how the record of these noises was made. Were they taken from an open wire toll line as in the other cases, or were they made from an analysis of the rectifier wave shape? Did the influence correspond to the frequencies on the direct current or alternating current side?

It is stated that the latest design of TIF measuring set operates along the same basic lines as the original TIF meter. The developmental model the writer has been using for factory measurements uses a vacuum tube. This limits the measurements to those in which the ratios of 2 quantities are used so that the performance of the tube does not influence the measurements. At times this is inconvenient, and it is understood that the latest model does not contain tubes. The writer should like to suggest also that it might be desirable to give a diagram of the circuit of the new meter with the permissible tolerances for the various circuit constants similar to that given in Osborne's original paper.

J. M. Barstow, P. W. Blye, and H. E. Kent: J. J. Smith's first question has to do with the TIF weighting assigned to 60 cycles per second. The weighting of 1 assigned to this frequency is only roughly correct as an indication of the interfering effect of 60 cycles per second. Since the fundamental frequency component ordinarily is not important from the noise standpoint, the exact value of the weighting assigned to this frequency was not considered important as long as it was sufficiently small to make the contribution of 60 cycles per second to the TIF negligible in the usual case. There appeared to be some merit to a round figure of unity for the TIF of a 60 cycle sine wave. Since this value was sufficiently low to meet the above requirement, it was adopted.

The records of rectifier noise were obobtained from the voltage and current waves in the a-c supply circuit to a commercial rectifier system. The recording device was coupled to the power circuit in each case through a simple network that weighted the various harmonics present in proportion to frequency, and thus simulated coupling between a power circuit and a telephone circuit. The resulting recorded noises were, therefore, intended to represent those arising by electric and magnetic induction in an exposed open wire toll circuit from harmonic voltages and currents, respectively, in the a-c supply circuit to a rectifier.

Thus far, no consideration has been given to the preparation of manufacturing specifications covering a revised TIF meter, and it is not possible, therefore, to give a detailed circuit diagram with allowable tolerances for the various elements as requested by Smith. However, there is given in figure 1 of this discussion, a circuit diagram of the most recent experimental model, which operates along the same basic lines as the original TIF meter, and does not employ an auxiliary amplifier.

In adopting the revised TIF weighting curve, the joint subcommittee on development and research of the Edison Electric Institute and the Bell System has not to date recommended tolerances as to the departure of individual meters from the desired characteristic. It seems reasonable to believe, however, that individual instruments will give TIF readings within 10 per cent of the true value in the average case if their networks are so designed that their weighting curves depart from the desired curve by not more than 10 per cent in the range from 400 to 1,800 cycles per second, and by not more than 20 per cent in the range below 400 cycles per second and between 1,800 and 3,500 cycles per second. Above 3,500 cycles the chief requirement is that the individual curves do not exceed the desired curve.

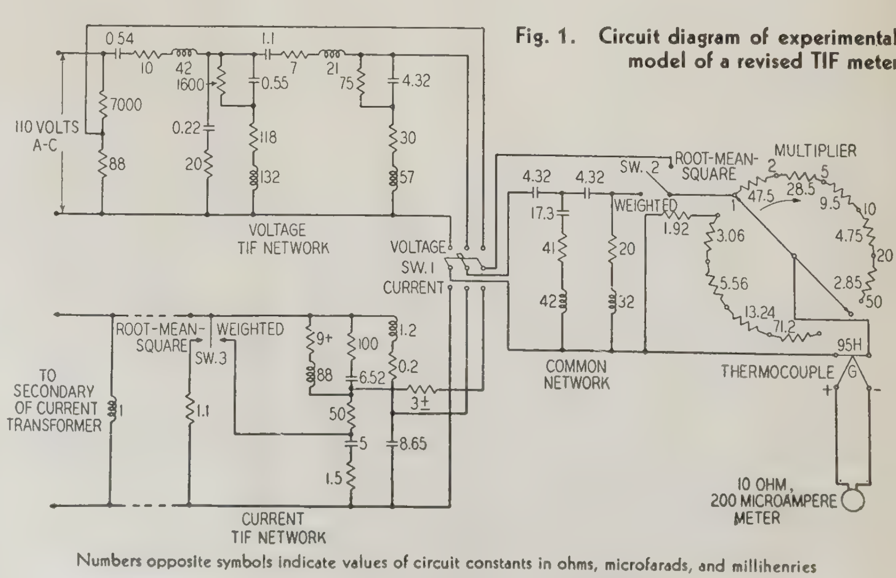


Fig. 1. Circuit diagram of experimental model of a revised TIF meter

Numbers opposite symbols indicate values of circuit constants in ohms, microfarads, and millihenries

A Cable Code Translator System

Discussion and author's closure of a paper by A. F. Connery published in the November 1935 issue, pages 1162–66, and presented for oral discussion at the communication session of the winter convention, New York, N. Y., January 28, 1936.

H. H. Haglund (Western Union Telegraph Co., New York, N. Y.): A. F. Connery has produced a remarkable translator system, having at least one important advantage over older systems such as have been in use in both England and America for several years.

In the older systems the frequency is only doubled, in going from 3 current to 2 current, but usually cable code circuits are so slow that increasing the frequency 3 times, as Connery does, has no detrimental effect upon the accuracy of transmission and it produces a signal that can be read by intermediate repeater stations. This obviously is an advantage of this system over the older ones in which the signals are unreadable without the use of rotary translators to convert the 2 current signals to the original cable code form.

The likelihood of undetectable errors appearing in the new system, however, seems greater than in the older systems. The accuracy claim Connery makes for the 3 current code is based largely upon the fact that deformation of signals, commonly called drop-outs and runs produce additional zero signals or spaces, which the receiving operator notices and corrects. A drop-out or run in this system might easily change a dash into a dot, which would pass unnoticed by the operator. In 2 current systems in which a dot is represented by 2 intervals of marking, dashes by 2 intervals of spacing, and spaces by one interval marking followed by one interval of spacing, drop-outs will produce spaces exactly as in the original code and runs will obliterate the spaces so that both types of transmission errors become apparent to the operator.

Connery's translating equipment seems much simpler than that employed in the older systems. This is, of course, a great advantage since apparatus costs are becoming of greater and greater importance. Business carried over cable circuits is high-class traffic, however, and apparatus costs must not be allowed to stand in the way of correct performance. The old equipment performs very well and the writer assumes this new apparatus does also. In writing of translator *23DW*, however, Connery says, "The principal advantage is that a small misadjustment of the dot-dash adjusting rheostat will not result in recording dots for dashes or vice versa." This implies that translator *23RY*, which is the type used for repetition into the cable, may require critical adjustment.

A. F. Connery: H. H. Haglund states in his discussion that undetectable errors may be more likely to occur in the new cable code translator system than in the older systems. In actual practice this condition has not been found. The translator is not required to be in synchronism with the received 2 element signals; thus a possible source of trouble is eliminated. In general, the landlines used in connection with cable circuits are worked well below their maximum speed, thus resulting in wide margin of apparatus adjustments.

It has been found that the advantages of translator *23DW* over the type *23RY* are so very slight that only type *23RY* translators are being used now. The margin of adjustment of the dot-dash adjusting rheostat depends, of course, upon the variation in the 2 element signals. As stated before, the landlines are operated below their maximum speed and the variation in the 2 element signals is small.

The "Comet"—A Diesel Electric Unit Train

Discussion and author's closure of a paper by A. H. Candee published in the November 1935 issue, pages 1240–45, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., January 30, 1936.

R. L. Kimball (Federal Power Commission, Washington, D. C.): A. H. Candee's paper and subsequent discussions have given a very clear picture of the adaptation of Diesel engine power to a high speed passenger train. This paper, and particularly P. A. McGee's discussion, may have raised a question as to the future prospects of this form of electrical propulsion.

Both the electric locomotive and Diesel powered equipment have a definite field in our transportation scheme. There are 3 factors that make possible and desirable the operation of Diesel equipment. Where a reduction in train weight is possible, as in the high speed streamlined equipment described by Candee, it is possible to mount on the train a Diesel engine of sufficient horsepower capacity to obtain good operation. This would not be feasible with the weights of existing standard passenger rolling stock. For switching locomotives the Diesel engine has a marked advantage over the steam locomotive because of the low speeds involved. The steam locomotive is unable to deliver its full horsepower at the rim of the driver at these low speeds. Although the rated horsepower of the Diesel engine may be considerably less, neglecting efficiency, practically the full output of the engine can be delivered to the driving wheels at all speeds by means of electrical transmission. In this way, although the horsepower rating is considerably less, the performance of the Diesel powered switching locomotive is superior to that of the steam locomotive used for comparable service. In some cases it is desirable to eliminate all steam maintenance facilities. This is especially true on light traffic branch lines. The Diesel powered equipment makes this possible in a number of cases.

Where the volume of traffic is sufficiently heavy, the demonstrated savings resulting from electric operation are sufficient to pay for the added investment and maintenance of the overhead distribution system. In such cases the investment in Diesel generating equipment on mobile units would be extremely heavy. This type of operation is distinctly in the field of the electric locomotive. At the same time the Diesel equipment is an extremely valuable adjunct. By means of its use it is possible to avoid the expense involved in stringing wire over light traffic branch feeder lines and infrequently used switching and industrial tracks. Without the use of the Diesel equipment some steam operation would have to be retained or the cost of the electrification would be disproportionately increased.

The writer believes, therefore, that Diesel equipment and the electric locomotive are allies rather than competitors, and that their combined use will result in more efficient operation.

P. A. McGee (Reading Co., Philadelphia, Pa.): A. H. Candee's paper is, the writer believes, the first presented in this country to explain the exact application of a light weight train unit to a particular service, and it should be found very useful both to railroad engineers and operators.

The first light weight trains having internal combustion power plants sacrificed the inherent operating economies possible with reversible movement in order to simplify the design with one direction trains. The New Haven "Comet" with control at both ends and reversible movement marks a decided advancement in the design of such trains. The double power plant also will be much favored by many railroad engineers, especially on long runs between terminals. These advantages, of course, must add somewhat to the first cost of the equipment.

One of the most interesting features of the "Comet" is the drive at both ends of the train. Opinion is quite divided on the desirable and permissible drive distribution. Where the motive power is supplied by separate locomotive units, it is naturally placed at the head end for normal movement. With electric multiple unit trains the leading coach or even the first two or 3 coaches may contain no motive power, and such trains operate satisfactorily at speeds up to 70 miles per hour. The motive power and drive are carried on the leading trucks of the Burlington and Union Pacific trains. In the case of the Gulf, Mobile, and Northern power unit the power plant is carried on the leading truck with the drive on the second truck. In Europe the much discussed "Flying Hamburger" has its drive on the center truck of the articulated 2 car train. If all these drive-distributions prove satisfactory, there should be little restriction in the arrangement of train power plants and drives. This freedom should decidedly favor a distributed drive on many of the axles with both Diesel-electric and straight electric power.

Another feature of the "Comet" that must impress the motive power departments of our railroads is the large amount of power required for auxiliary purposes on such a small train. The necessary power for auxiliaries must be supplied through the tractive power of locomotives where axle driven generators are employed, through head end power plants where Diesel-electric train units are employed, or possibly direct from the contact lines where electric motive power is employed. The additional

weight and power required in each of these cases may be of small importance at low train speeds, but it becomes of great importance at high speeds, for any resistance caused by additional weight increases the required motive power directly in proportion to an increase in speed. This holds on both level and grade.

Candee employs Davis's tractive resistance formula with an arbitrary assumption of reduced air resistance coefficient and an arbitrary assumption regarding the train makeup. The writer believes the resistance values thus developed for the "Comet" will be found to be fairly accurate. Using Davis's values for journal and flange resistance, the writer found a simple method for computing the total resistance of any given train, which gives a total resistance of 2,350 pounds on level track for the "Comet" weighing 272,000 pounds at 90 miles per hour as compared with Candee's value of 2,500 pounds at the same speed.

Now that the "Comet" is in regular operation it should be a simple matter to check the resistance values at various speeds and the writer would like to ask Candee whether such checks have been made, and if so, what the results have shown.

One of the greatest values of a paper such as Candee's is the opportunity it offers for comparing the performance of the motive power considered with other possible types of power, and in this connection the author is to be congratulated on the accurate comparison he gives for the various types of trains.

The light weight small, articulated cars employed on the "Comet" and similar trains with Diesel-electric motive power could be employed with other types of power, and it is interesting to note the power requirements and total train weight if either steam or straight electric motive power were employed. In any such comparison it is always difficult to appraise properly the accelerating characteristics of a given equipment unless the average distance between stops is relatively short. On a through run, such as the "Comet's" run between Boston and Providence, it would always be possible with excessive speed on the down grade sections to make up time that might be lost during accelerating, and on the up grades. This procedure is quite common on many roads. For this reason, emphasis is laid on the maximum speed at which a train may be run, regardless of where or how this speed is obtained, and it is generally obtained on a down grade where the actual amount of motive power has little effect on the speed. This procedure has certain economic advantages from the point of view of motive power assignment to a given train, but operators are becoming interested in maximum schedules with a given maximum speed and the writer proposes to show just how high accelerating rates up to high speeds and availability of large amounts of power on a grade can favorably affect a schedule on a profile such as between Boston and Providence.

Table I of this discussion explains the basis for such an analysis with trains comparable to the "Comet" and employing Diesel-electric, steam and distributed electric motive power. The net available train length of the "Comet" is 160 feet and, excluding equipment it weighs approximately 725 pounds per foot. Particulars of the Diesel-electric train are taken from Candee's paper. For the steam power, a locomotive of about 600 horse power at the driving wheels would have a free running speed of 90 miles per hour on level track with a 160 foot train having the same weight per foot, excluding equipment, as the "Comet." Such a steam locomotive with tender would weigh about 200,000 pounds and have an over-all length of about 50 feet. The electric train with motors having 456 horse power output would have a free running speed of 90 miles per hour on level track with a 160 foot train. The motor equipment would weigh not over 30,000 pounds.

Table I—Comparative Data of the "Comet" and Equivalent Steam and Electric Trains

	"Comet"	Steam	Electric
Weight of train per foot excluding equipment, pounds	725	725	725
Net available length, feet	160	160	160
Total length including motive power, feet	207	210	160
Approximate weight of motive power equipment	100,000	200,000	30,000
Weight of load, pounds	22,000	22,000	22,000
Total train weight with load, pounds	272,000	335,000	164,000
Total train weight, tons	136	167.5	82
Tractive resistance, level track at 90 miles per hour, pounds	2,350	2,535	1,900
Horsepower at drive wheels, level track at 90 miles per hour	565	609	456

Table I of this discussion indicates that if locomotive designers were interested in small output steam locomotives the extra weight over small Diesel-electric trains is not excessive, and that the wonderful weight efficiency resulting in light weight Diesel-electric trains is caused by the light coaches rather than the Diesel-electric power. The small Diesel-electric equipped trains have many advantages over steam trains, and these advantages may be attributed to the flexibility of the electric drive.

The possible reversibility of the Diesel-electric drive as developed for the "Comet," and the lack of engine house requirements with the Diesel-electric power plant, together with its fuel efficiency and lack of disagreeable exhaust, are quite important factors in its adaptability and economy in such a service as the run between Boston and Providence. Diesel-electric power has also a slight accelerating advantage over steam for light weight trains such as the "Comet," as shown later in this discussion, although it is doubtful that such advantages would result with large trains.

To exploit fully the advantages of light weight equipment it is necessary to employ a direct electric drive supplied with power from a contact line. As shown in the third column of table I of this discussion, a light weight train with the same available length as the "Comet" would weigh only 82 tons (loaded) against the Diesel-electric train weighing 136 tons, and a comparable steam train weighing 167.5 tons. The possible economy in first cost of such an electric train over the Diesel-electric train is considerable, and its operating cost over both Diesel-electric and steam is also very considerable, provided the traffic density could justify the cost of the electric distribution system. An 82 ton electric train as shown in table I of this discussion, should take not more than 4 kilowatt hours per train mile, excluding heating, on a 44 minute run between Boston and Providence. With power at 0.075 cents per kilowatt-hour, the power cost would not exceed 3 cents per mile. Candee gives a fuel cost for the Diesel-electric "Comet" of 3.4 cents per mile, and when the cost of lubricating oil is added for the Diesel-electric plant it will be seen even for the item of power cost, where the diesel power plant normally excels, that light weight direct electric drive is the most economical.

The most important factor, however, with the operation of these high speed trains is, as already indicated, the relation between their maximum and schedule speeds. In the profile shown in figure 4 of the paper there is an equivalent grade of about 0.6 per cent for a distance of 6 miles on the run between Boston and Providence. Should the 3 trains as outlined in table I of this discussion start from the bottom of this grade they would accelerate and complete their runs to the summit of the grade in a manner shown in figure 1 of this discussion. The "Comet" would take 423 seconds, the equivalent steam train would take 456 seconds, and the electric train would take 345 seconds. The "Comet" would attain a speed of 64 miles per hour, the steam train a speed of 59 miles per hour, and the electric train a speed of 75 miles per hour in 180 seconds. Should all 3 trains conform to the time limitations near Boston and Providence, which occupies 14 minutes, make a second stop at the base of the 0.6 per cent grade, and accelerate as shown in figure 1 of this discussion, the average speed required between the summit and Boston switch with a 44 minute run between Boston and Providence, would be approximately 113 miles per hour with the "Comet," 125 miles per hour with the steam train and 93 miles per hour with the electric train. With normal operation, a start is not made on the 0.6 per cent grade, and Candee's figure 10 shows a maximum speed of 90 miles per hour on the down grade with the "Comet." Under corresponding speed re-

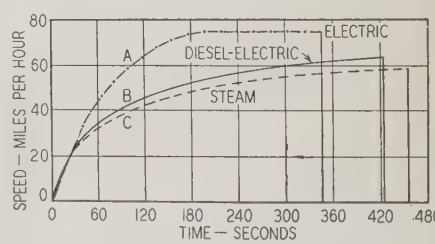


Fig. 1. Speed-time curves for 6 miles of 0.6 per cent positive grade

	Curve A	Curve B	Curve C
Type of train	Electric	Diesel-electric	Steam
Weight, tons	82	136	167.5
Length, feet	160	207	210
Horsepower at drive wheels	456	565	609

strictions, the electric train should not exceed 85 miles per hour on the down grade, although it would be necessary to exceed 95 miles per hour with the steam train considered to accomplish the run in 44 minutes. Any release in the speed and time limitations near Boston and Providence would, of course, cause a corresponding reduction in the maximum speed required to meet the schedule.

It should be recognized that considerable work remains to be done in studying the application and operation of high speed trains and our thanks are due to Candee for his very interesting and instructive paper on the subject.

A. H. Candee: The writer agrees with R. L. Kimball that both electrification and Dieselization have a field in railroad transportation, and would also like to advance the idea that neither of these is competitive with steam power (from a cost standpoint) in some types of service. The ultimate use of all 3 of these systems may be anticipated, the selection of motive power type being made on the basis of economies or by local conditions which force the use of a particular method.

P. A. McGee has asked whether the train resistance values have been checked in actual road service on the "Comet." This has not been done, because of the cost of such tests. Unless such tests are made carefully, they may be of little value, or may even be misleading. It may be pointed out, however, that the ease with which the "Comet" schedule is being maintained indicates that the train resistance values as used in the calculations are high.

The author agrees with McGee that by electrification it is possible to exploit fully the advantages of light weight rolling stock. In the service to which the "Comet" has been applied, however, electrification is out of the question.

Sliding Contacts — Electrical Characteristics

Discussion and author's closure of a paper by R. M. Baker published in the January 1936 issue, pages 94–100, and presented for oral discussion at the synchronous machines session of the winter convention, New York, N. Y., January 29, 1936.

T. T. Hambleton (General Electric Co., Schenectady, N. Y.): It should be of interest to cite some previous experience in connection with the influence of film on the collection of current through sliding contacts.

One notable case occurred in Norway in 1930. Four large 25-cycle 10,000-ampere 580-volt converters were installed in an electrolytic zinc refining plant on the west coast. The humidity approached 100 per cent at night and ran from 70 to 80 per cent during the day. There were frequent periods of rain or fog during which 100 per cent saturation existed.

Approximately 30 tons of free oxygen was released each 24 hours in the cell house adjacent to the converter station. This gas carried with it a fine spray or fog of the electrolyte containing free sulphuric acid and zinc sulphate. There was evidence that the station ventilating air carried in a portion of this free oxygen and acid fog.

The formation of film on the sliding contact surfaces was very rapid and heavy but did not occur elsewhere on exposed copper. It was assumed that the electrical energy released at the sliding contacts activated the chemical reactions in this favorable atmosphere. The growth of the film, starting with a clean surface, was indicated by the usual procession of light interference colors during the period while the film thickness was of the order of magnitude of wave lengths of light. Beyond this point the color was blue-black and the thickness several mils.

A test was made by passing direct current from the film through a drop of distilled water to a carbon pencil. This completely removed the film and deposited metallic copper on the carbon. The progressive reduction of film thickness was indicated by the usual light interference colors. Since there was no noticeable inactive residue it was concluded that the film was largely if not entirely a copper compound (probably copper hydrate).

The contact resistance of the film was measured by short-circuiting an ordinary dry cell through an ammeter and carbon pencil ground down to a flat end area $^1/_8$ inch square. The short-circuit current determined on freshly cleaned copper and on the film indicated an additional resistance in the film and contact of $^1/_{10}$ ohm for this $^1/_8$ inch square area.

The performance of the converters was as follows: Some sparking occurred during the early stages of filming but perfect commutation was obtained when the film became uniform. Instability appeared in the heavy film in that small areas burned off, resulting in low contact resistance and overloading of the brushes contacting these areas. This burning spread the areas until severe sparking required the commutator to be cleaned completely. The cycle then repeated.

A special grade of graphetized carbon brush was secured which produced very much less film. Stable film and successful commutation has continued to the present time. The same difficulty occurred on the slip-rings and was overcome by selecting a suitable grade of brush.

The lubricating effect of an adsorbed film of water has also been demonstrated in a large number of instances in connection with the slip-rings of large synchronous converters. In these instances a relative humidity of less than 15 per cent in subzero weather has been accompanied by a several hundredfold increase in rate of brush wear particularly in heavy metallized brushes. The practice of humidifying the air at such times has completely eliminated excess brush wear.

This paper is to be commended, and further investigation and study of this subject is urged.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In this paper the author has presented a wealth of evidence to the effect that the formation of oxide films and the spreading resistances in the brush are probably the principal factors in the mechanism of sliding contacts and in the explanation of their behavior. At any rate, he has left scarcely any doubt that the oxide film is an important factor with the materials commonly used in practice. He has also explained how this semi-insulating oxide film breaks down at certain points when the current is changed from very small to large values. He assumes that after the breakdown metal bridges extending through the punctures in the film establish contact between the rings and the carbon surfaces. In other words, his conception must be somewhat as shown at *a* in figure 1 of this discussion.

In so far as Baker himself has demonstrated in some of his unpublished work that there is a definite elasticity in the sliding surfaces of the brushes, I prefer to picture the mechanism of establishing contact between the brushes and the rings as shown at *b* in figure 1, in which it is assumed that because of the elasticity in the carbon, certain crystals reach through the puncture and make contact with the ring, as shown at *c*, or, that in some cases such contact may be established by loose particles of carbon such as shown at *d*. It may be that the holes in the film after leaving the brush and before returning to the same or reaching some other brush may reoxidize, but even if this should be so, the new film in the opening will undoubtedly be much thinner than the rest of the film, as indicated at *e*. Therefore, the very thin film at such points as *e* will naturally break down again as soon as new contact is made with a current-carrying carbon. (In the figure the thickness of the oxide film has been greatly exaggerated in order to illustrate more clearly the principles discussed.)

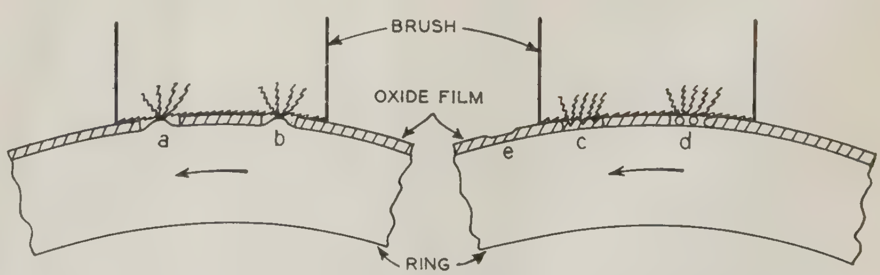


Fig. 1. Illustration of methods of transfer of current between slip-rings and brush

I favor the theory indicated at *b* because it more readily fits in with the observations

made by L. R. Ludwig and myself and covered in our paper "Sparking under the Brushes of Commutator Machines" (ELEC. ENGG., March 1935, p. 315–21). With the assumption of small carbon bridges carrying the current, it can be readily seen that if but few such bridges exist and the current is suddenly raised, there will be an appreciable voltage across the bridges and great energy concentrated in them before any new breakdowns and bridges can be formed. This theory naturally suggests the possibility that under such conditions some of the carbon bridges become incandescent and burn, thus leading to the sparking that we have observed with very sudden increases of current densities in the brush contacts.

M. S. May (Speer Carbon Co., St. Mary's, Pa.): The author has brought out very interesting facts in a discussion which has been principally from the experimental and theoretical point of view. His conclusions are verified by observations made in actual operation, and some outstanding examples may be of interest.

He emphasizes the fact that contact drop changes with load variations as a result of the breaking down of the oxide coating. It is well known that the friction on large machines and its resulting noise similarily change quickly with any change in load. The reduction in friction with increased load can probably be explained by Baker's theory regarding the destruction of the oxide coating. A 1,000 kw generator being tested by the manufacturer was run at very light load to wear in the brushes. A chattering was set up which resulted in pitting of the commutator when normal load was later put on the machine. The commutator was, therefore, sanded and the brushes run again at full load, no trouble being encountered. The explanation would seem to be that running in at light load formed too heavy an oxide film resulting in high friction and brush vibration. Running in at normal load seemingly prevented the formation of excessive coating.

I have been told that silver oxide has essentially the same electrical conductivity as silver itself. Might this not be the reason for the straight line drop curve which the author obtained with a silver ring?

R. M. Baker: The discussion by R. E. Hellmund as to the process by which the oxide film in a contact is broken down by the passage of current is quite appropriate, for this is a point of prime importance, and one which to date is only slightly understood. The writer feels that an understanding of this point would go far in explaining why the contact drop is usually greater at one polarity than at the other and many of the other commonly observed polarity effects in sliding contacts.

One is forced to the conclusion that the reduction in contact resistance at the higher currents must be caused by some more permanent change in the oxide film than merely the change in resistivity of the oxide with temperature, for if the contact resistance is lowered by the passage of heavy current, the contact regains its high resistance operating at a low current only after operation for several hours at the lower current. This is more time than is necessary for the equalization of the average temperature of the ring and is infinitely more time than would be required for the temperature equalization of the small areas of the film which are active each revolution in carrying current. The suggestion that the oxide film is broken down by the building of metal bridges through the oxide was given in this paper because it has been rather definitely established by other investigators that this is the explanation of the coherer effect or the breakdown in low pressure stationary metal-to-metal contacts. The type of breakdown suggested by Hellmund very probably plays an important part in the performance of a sliding contact, for here the surface of the ring or commutator is being continuously abraded by the brushes. It is believed that this effect accounts almost entirely for the change in resistance of the small contact operating in comparatively oxygen-free atmospheres as described in this paper, for the purity of the gases used was not good enough alone to effect a reduction of the oxide.

As M. S. May explains, there is a tendency for the friction of a sliding contact to build up to a high enough value at light loads to cause the brushes to chatter, whereas the same brushes operate quite satisfactorily at full load. This is undoubtedly due to the change in the nature of the contacting surfaces, which are in turn affected by the amount of current flowing through the contact. It may be that this change results from the change in rate of brush wear with current, or as May suggests, by the breaking down of the oxide film. The effect cannot be accounted for entirely by changes in the oxide film, however, for the writer has observed a similar effect with carbon brushes operating on carbon rings, in which case no oxide film exists.

It is often heard that the reason silver makes such a good contact material is because silver oxide is conducting. Practically all of the oxides are semiconductors having many times the resistivity of the metals, and as far as the writer knows, silver oxide is no exception. The rate of oxidation of silver, however, is low, and when formed the oxide is easily removed from the metal surface by abrasion. This probably accounts for the low contact drop observed when a carbon brush is operated on a silver ring. Silver is also peculiar among the metals in that its oxide is unstable in air at a temperature of about 150 degrees centigrade, so that if a stationary contact made from silver should tend to build up a high contact resistance through oxidation, the temperature of the contact would not go very high before the oxide in the contact would start to dissociate at the current-carrying areas, and the contact resistance would be lowered. The straight line volt-ampere characteristic exhibited in this paper was obtained, as explained, only after the small silver slip-ring had been heated with a gas flame, although the contact drop on this ring even at room temperature was only about a quarter of that of the nickel ring.

The observation of T. T. Hambleton on the case of abnormal film formation are most interesting. This is a field trouble often occurring around chemical plants and other places where pollution of the atmosphere causes the formation of excessively thick films on the rings and commutators of electrical machines. The only solution to this trouble seems to be, as Hambleton indicates, applying a grade of brush with sufficient cleaning action to prevent the film from building up.

Rapid wear of metallized graphite brushes, when the moisture content of the air becomes low, is something which apparently was not appreciated until within the last 5 years. There is also ever-increasing evidence that similar trouble is encountered with carbon or graphite brushes during extreme cold spells, and this problem will undoubtedly receive more attention in the future.

The "Biway" System of Electric Platforms for Mass Transit

Discussion and author's closure of a paper by Norman W. Storer published in the December 1935 issue, pages 1340–47, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., January 30, 1936.

R. F. Kelker, Jr. (nonmember; consulting engineer, Chicago, Ill.): The writer wishes to call attention to one particular phase of this proposal in which he is personally interested, and that is the transportation phase. The mechanical and electrical parts of the device are clear.

From the transportation point of view, the paper considers a problem that is constantly changing, and needs new devices and methods to give the service required by the people in major metropolitan areas. The author proposes to operate a device that would carry 60,000 or more people an hour for short distances, conveniently, without apparent jostling, and at a reasonable speed.

Such a device, of course, warrants the close and thorough analytical attention of all engineers interested in transportation. Storer has covered nearly every phase of the problem in his paper.

The usual method of handling peak loads has been to increase traffic or transportation units in peaks, and then make reductions for off-peak conditions. Here is a proposition of operating at "full steam" at all times, but the vast difference is that, as compared with street car operation, the tracks are kept in place, there are additional cars in the car barns, and additional men must be found to meet the peaks.

The "biway" would run practically at a constant speed throughout the period of operation. If the load changes, the only difference is in power consumption. Now the point arises whether power cost in the off-peak periods will be less than the additional expense of meeting the demand for peak loading in ordinary forms of transportation.

Apparently it will, and it will be a novelty to the American riding public not to experience the unsatisfactory loading conditions in off-peak periods, because all street railway properties are operated on the idea that if they can get enough traffic in

off-peak periods, such traffic will help to meet the cost of the peak periods.

In fact, in the last several years the diminution in business in the off-peak periods has presented a financial difficulty in operation.

Referring to seating capacity of the "biway," the ratio of 50 standees to 100 people seated would be unknown in America. American subways carry about 400 standing for 100 people seated. In street cars the ratio is about unity.

Here is a proposal for a transportation device in which the number of people seated would be more than twice the probable number of people standing, and that is something to strive for, particularly where there are heavy traffic movements in short periods of time.

In congested centers, where the use of the properties are intensive, obviously a scheme of this kind or such a device is adaptable. The job, of course, because of its great capacity, is to find a place in which there is enough business to require its use.

From the transportation point of view, it is a giant. Now where is the giant's job? Storer has suggested a location in New York. Unquestionably it is a good suggestion. The inadequacy of service in that city has been demonstrated a number of times, but the chief difficulty has been in finding an operating unit of sufficient safety to justify even considering it as a daily operating function.

Now if Chicago had had a scheme like this in operation during the recent world's fair, that is a biway with a loop at Monroe Street in Grant Park, to carry the traffic to and from the fair grounds, with a distribution throughout the grounds, and at the same time had had another loop south of the fair grounds, a far better class of transportation could have been provided.

The substitution of continuous service for intermittent service is the chief factor. Here is a reliability that is not dependent upon traffic conditions or upon the operator of a car or bus.

The use of gates alongside the slow moving platform has been discussed by the author. The gates might be difficult to handle, but when the slow speed and the slight possibility of being dragged are considered, the difficulty is somewhat diminished. Street cars were operated without doors until doors were found to be necessary. The same situation would develop in the use of the biway.

The writer is pleased to have the chance to say to electrical engineers that they have developed something in the transportation and the civil line that looks good, something that will stand analysis from the electrical point of view, and something that is needed in metropolitan areas. The engineer's job is to analyze and find a place to put a thing, and then develop it. That is the job that Storer has placed before engineers. It is a unique situation in which you have a transportation unit developed in the abstract. Usually engineers are given a problem, and they solve the problem in the ordinary technical way, in concrete form; but here is something in the abstract. The writer is very glad to have an opportunity to say that from every point of view with which he is acquainted, Storer has an idea that is usable, and there are places in which it can be used successfully.

P. M. Lincoln (Cornell University, Ithaca, N. Y.): The writer has been much interested in this suggestion, this dream of Storer's; however, there are some questions to be asked. One thing Storer mentioned is the cost. Of course, cost is important in any engineering undertaking; both fixed charges and operating cost are important. Although Storer does not set a fixed charge rate definitely, he does suggest the size of the annual charges at 6 per cent interest.

If an enterprise of this kind were carried out by a private concern, 6 per cent would not be sufficient to apply to the first cost in order to get the fixed charges. If the writer were asked for his opinion on this matter as a consulting engineer, he would use at least double that figure. Of course, if such a project were to be carried on by a municipality, the item of taxes presumably would be absent; at least, it would be absent on the surface. Somebody would pay them, but they would not be applied to that particular project; therefore, the writer questions that particular figure. The writer doubts that Storer suggested that figure as the proper fixed charge rate to apply to the first cost.

There is one other point that should be discussed and that is the matter of possible accidents in transferring from the stationary platform to the local platform, and from the local platform to the high speed platform. There is plenty of precedent to indicate that it is perfectly safe for a passenger to transfer between a stationary platform and a moving platform at a speed of 3 miles per hour, and between 2 platforms running at a relative difference in speed of 3 miles per hour. There is plenty of precedent in Chicago, in Paris, and in other places that indicates it can be done in perfect safety.

At certain periods of the cycle, the relative speed of the local passenger platform and of the high speed platform passing the local platform would be very much in excess of this 3 miles per hour, which has been demonstrated to be a safe speed. What are the means of protecting the passenger when transferring from a stationary platform to a platform running at a speed much higher than 3 miles per hour, and from the local platform to the high speed platform running at a speed of from 14 to 17 miles per hour?

Just what means can be taken to protect the passengers is not clearly pointed out in the paper. The writer believes that a considerable item of expense in the operation of any transportation system is the suits brought by those who have suffered accidents, or those that claim to have suffered accidents.

Just how the avoidance of accidents during transfer is to be accomplished in this scheme is not entirely clear. Possibly the author can give a little more concrete idea as to how that can be accomplished.

Alfred Brahdy (nonmember, Board of Trnasportation, New York, N. Y.): After the thorough manner in which N. W. Storer has described the proposed "biway" system of transportation there is little to be added by the writer, whose field is the planning of the conventional type of urban mass transportation systems. The writer's problem has been the provision for rush hour traffic at a cost for structure and equipment that does not involve too great an expense above that necessary for the normal traffic requirements.

The transportation engineer now is offered an embarrassment of riches in Storer's biway system, for maximum capacity is available at all times, and the problem resolves itself into a consideration of whether this maximum capacity can be used during the off-peak traffic periods without impairing the project financially.

The biway system is estimated to provide 60,000 seats per hour in one direction, and there is no doubt that such capacity provides ideal facilities. The Eighth Avenue Subway of the Independent System, which has been in operation in New York since September 1932, is designed in structure and equipment on a basis of operating 10 car trains on a headway of 90 seconds, or at the rate of 40 trains per hour during the peak traffic period. The maximum number of seats past any point is 23,000 per hour, less than $^1/_2$ the estimated capacity of the biway. The total passenger capacity, seated and standing, on this subway is 90,000 per track per hour. It is expected ultimately to operate 11 car trains, which will increase the capacity, the stations and signal system having been designed to permit trains of that length.

The biway system has a tremendous passenger capacity, as Storer has pointed out, and its greatest field of usefulness is in the congested sections of the city, where there is heavy traffic for short distances.

In advocating any departure from the accepted methods of transportation, the engineers in public service are faced with great difficulties, because, contrary to popular belief, they have only limited funds at their disposal. In fact, it is generally difficult to get even small sums for research or investigations. Administrative officials responsible to the taxpayers for the economical expenditure of public funds are very hard to influence favorably in a proposal to use public money for the development of new types of facilities, even if these facilities promise to solve a difficult problem.

It took years of agitation to educate the public and its officials to the necessity of placing the mass transportation facilites of large cities underground where they would be free to move without interference from other street surface traffic. The arguments advanced against this type of transportation at one time by such organizations as chambers of commerce and merchants' associations, and even by engineers, show how difficult it is to change an established custom. This is an unfortunate situation and it is one that must be faced and overcome in advocating any new method of transportation, or anything else that is new, where action by governmental bodies is required.

Years ago cable cars operated across the Brooklyn Bridge to carry passengers from Manhattan to Brooklyn, where they transferred to elevated trains taking them to their ultimate destinations, and the operation of these cable cars demonstrated the adaptability of passengers to the mode of transportation. Traffic was so heavy that a train of cable cars would pull in at the station platform, people would board the cars, and a gong would sound for the trains to start without allowing time for closing the gates. The passengers were so accustomed to this that as soon as the gong sounded those

on the platform would step back, and the train would pull out. Although the writer does not know what the accident record was, it is known that the passengers who boarded those trains were accustomed to that method of operation. The regular passenger on any transportation system soon would become adjusted to any method in use. Difficulties will be experienced with the occasional traveler, with the traveler who happens to have an infirmity, and with habitually reckless persons.

L. W. Chubb (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): There has been a good deal of discussion about the safety of the "biway." Safety must be judged, and is judged by experiences and habits. People become accustomed to certain things that are real accident hazards. For years, doorknobs have been placed near the edge of the door where fingers easily can be caught and smashed. Everybody became accustomed to this and very infrequently pinched his fingers. Most people became accustomed to the old open streetcars with the running boards.

The public is used to the present subway station arrangement with a high platform and a congestion at stations. There is real danger of being pushed off the edge of the platform by such a crowd, and the resulting fall would be serious because of the velocity gained, the impact, and the danger of being run over. With the biway, this hazard is reduced greatly because the platforms are at the same elevation, the speeds are relatively low, and the chance of being pushed by crowds is practically eliminated, because of the elimination of stations and concentrated points of entry.

The 2 platforms are at the same level, the relative motions are slow, and a person crossing the barrier before the platform comes to rest has much less chance of injury than one going through a revolving door, in which agility and movements must be governed by the sudden changes in speed by the preceding person.

Since the platforms are level, it also seems better to omit the gates and thus avoid any bumping or catching of clothing and the risk of any lesser injury that may result from a simple fall. The writer would like to ask the author whether he feels that the gates are necessary between 2 platforms moving relative to each other.

L. A. Phillips (consulting engineer, New York, N. Y.): As one of the operators of the 1900 Paris Exposition moving platforms, the writer feels that he can answer several questions brought out in this discussion. The Paris platforms operated at constant speeds of 3 and 6 miles per hour about 14 hours per day, and carried as many as 50,000 people at peak loads. The total length was about 11,000 feet. The platforms were driven by 120 series-wound double-reduction horizontally-mounted spring-suspended motors, with an adhesion drive against the bottom of the I-beam mounted on the bottom of the platform, thus permitting lowering of the motor unit without interfering with the platform operation.

N. W. Storer mentions as an objection to the adoption of Putnam's platforms "the necessity for passengers to step from one moving platform to another moving at a speed of 3 miles per hour above or below its own speed. There undoubtedly would be many people unable or unwilling to do this, which would be a great handicap to the system. It would be equivalent to a moving stairway running at 3 times its usual speed." In fact, all users of the Paris platforms, over 7,000,000 of them, did this very thing, twice in getting on, and twice in getting off, and there was not a single serious accident during the entire period of operation, from May to November.

The writer would like to call attention to the fact that the limiting factor in loading at stations was the turnstiles, which were the "bottle neck" of the system, for as fast as passengers got through the station gates, they stepped on the narrow stationary platform thence to the slow speed platform, on which they walked diagonally to the high speed, and wider, platform. There were no seats or gates on the Paris platforms, only a series of vertical posts for hand support, and most passengers never used these, after the first 2 or 3 trips.

The power consumption at peak loads was less than 350 kw and all bearings were of the plain babbitted type. With modern roller or ball bearings, this figure would be less.

N. W. Storer: In closing, the writer wishes to express his sincere appreciation of the excellent discussions present on this paper. Everybody has suggested some feature that is important at this time, when plans are developing.

It is notable that the electrical and mechanical features of the "biway," including the control system, the method of driving, and the platform construction, were scarcely mentioned. Practically the entire discussion centered on the questions of the economy of a system that operates with full capacity all of the time, and whether gates should be used between platforms. R. F. Kelker, Jr., calls the biway a giant, and asks where it can be used, then answers the question himself, approving the plan suggested during the presentation of the paper, for a biway loop on Fifth Avenue from 51st to 34th Streets, to Eighth Avenue, back on 33d to Madison Avenue, and up to 51st Street, closing the loop at 51st and Fifth Avenue. He also pointed out places in Chicago where it would have been very valuable during the recent world's fair.

Alfred Brahdy has some doubts about the economy of the biway during off-peak hours. It is quite natural for a transportation engineer to look apprehensively at any system that operates so much of the time with empty seats. It looks very inefficient and expensive. It is inefficient, viewed purely from the standpoint of carrying more seats than are necessary to satisfy the patrons, but the biway system is more efficient from the standpoint of service than is the ordinary subway, for it maintains the same high class of service at all times; therefore, it will attract many more people than a system that cuts down the service during the off-peak hours.

The question of operating expenses must be considered with over-all cost of operation, and a comparison of the biway with the Eighth Avenue Subway indicates that the biway is much less expensive, at least in some particulars. Taking Brahdy's figures for the rush-hour load on the subway—40 10 car trains per hour carrying 90,000 people, 23,000 of whom are seated—the biway would carry the same total load with 60,000 passengers seated, at the same average speed, with 6 times as many stops per mile, with not more than $^1/_3$ the power consumption and $^1/_{10}$ of the maximum power demand.

During light load periods, the biway would operate at full speed with about the same power consumption as the average requirement of 80 subway cars per hour. It will be noted that this is only $^1/_5$ of the cars in use during the rush hour. These cars would seat less than 4,500 passengers or only 5 per cent of the rush-hour load, which would seem to be as small a load as would be expected during even the lightest hour. These cars undoubtedly would be operated in shorter trains than those in the rush hour, but at much less frequent intervals, so that the service would be inferior to that of the biway, even though the biway local were making only 40 stops per hour instead of 85. For any traffic requiring more than 80 cars per hour, the biway would operate with less power than the subway, and the all day average probably would not be much more than $^1/_2$ the power consumption of the subway. The cost of power would be even less than proportional to the average load, because of the uniform load taken by the biway.

Other operating costs, such as for platform guards, also would be reduced during the off-peak hours. The cost of maintenance of the platforms and operating equipment would be low in any case because of the extreme simplicity of construction, the comparatively slow speed, and freedom from shocks and the stationary driving equipment. The cost of maintenance should be much less than that of the subway trains now in use, in spite of the platforms having a much greater average mileage. There seems to be every reason to believe that the biway is one system that can operate continuously at full capacity without excessive cost of operation, and at the same time furnish the very best of service.

In writing the paper, the great flexibility of the "biway" system was not sufficiently stressed to convey the idea that it could be anything but a giant so far as transportation is concerned. In fact, the biway may be installed with platforms much narrower than those shown, with carrying capacity quite suitable for smaller cities, or for certain districts in the largest cities. The biway can be installed in an over-all width of as little as 10 feet, or as much as 15 or 20 feet, if desired, and can be operated at express speeds of from 10 to 20 miles per hour, or even more, provided only that the line is made with proper curvature for the speeds.

Since presenting the paper, the scheme of operation has been analyzed further, and a comparison of the biway with the Eighth Avenue Subway has been made. It was found that increasing the length of the cycle of operations from 42 seconds to 60 seconds reduces the power consumption by 20 or 25 per cent, and that a further increase to 90 seconds will make a total reduction of 30 to 35 per cent. It appears, even with these conditions, that the biway still would be far ahead of the subway in point of convenience and in time saving. At the same

time, it would effect a considerable reduction in the cost of driving equipment, and would permit more time for transferring from one platform to another and, decreasing thereby the danger from accident. It is the author's opinion that the biway system eventually will be a real competitor of the subway for loops of considerable length.

The question of safety was discussed by P. M. Lincoln, L. A. Phillips, and L. W. Chubb. Lincoln feared that the accidents resulting from transferring at the wrong time might result in damage suits that would absorb a considerable part of the revenue. This was not agreed to by any of the other speakers, several of whom pointed out that the cost of accidents to transit companies does not exceed from 2 to 3 per cent of the gross income; moreover, if gates were used as shown in the paper, passengers could not transfer except at the proper time.

Chubb believes that people would readily accustom themselves to the system, and there would be no danger from accidents. He inquired whether it would not be possible to omit entirely the gates shown in the biway drawing. Phillips pointed out that the moving platforms at the Paris Exposition in 1900 had been under his charge, and that people found no difficulty in transferring from a platform running at 3 miles per hour to one running at 6 miles per hour. He questioned the statement made in the paper that danger of stepping from one such platform to the other was a reason that had helped to prevent their adoption in commercial service. Although there is no doubt that a large majority of people would be able to pass from one platform to another running 3 miles per hour faster or slower, there are many people who would find it difficult to do so, and the fact that 7,000,000 people did it at the Paris Exposition is not proof that everybody was willing to undertake it. However, if the contention is established that this difference in speed is perfectly safe for everybody, it could be applied to the biway system quite easily, and would effect a material saving in cost of operation to provide for people transferring with a difference in speed of from 2 to 3 miles per hour between platforms.

The author is entirely agreeable to omitting the gates. They have been included like some other things, to cover the most difficult requirement. A small bridge across the gap between the platforms, to be lowered like the steps of some street cars when the gates were opened, was considered. These were omitted as unnecessary and it is believed that the gates can be omitted for the same reason. It would be impossible to interlock the large number of gates required in such a system with the control so as to prevent its functioning until all gates are closed, as is done on subway trains; therefore, the operating mechanism would have to be trusted to open and close the gates at the proper times. Undoubtedly, there would be occasional failures of such devices, and one or more gates might stay open or closed. In such cases, it is possible that they might be more dangerous than if they were omitted entirely.

The author is impressed by the testimony of Kelker, Brahdy, Chubb, and Phillips in regard to people becoming accustomed to new systems, and he believes it would be just as easy to accustom them to operating without the gates. Certainly, every effort would be made to safeguard passengers. Suitable signals would be given for transferring, using gongs, whistles, red and green lights, or even broadcasting instructions by means of loud-speakers from electrical transcriptions. The passengers must be allowed to take care of themselves, just as is done in subway stations where crowds push around on the edge of the platform before a train comes in, or when the person crosses a street or gets on or off a street car. There always will be a few reckless persons who will deliberately transfer when there is a material difference in speed, and escape without injury. Occasionally a passenger may fall, but even then serious injury would be unlikely. Altogether, the biway would be as safe as any other known system of mass transit, or safer.

Lincoln is disturbed about the cost of financing the biway, and thinks 6 per cent, which was mentioned in the paper, is too low. He is quite right, if it is assumed that the system would operate on private capital, but a subway for the biway would have to be financed by the municipal government just as the present subways and streets have been. A city should finance it. As one engineer, who is in a position to know, said "the installation of the biway in the loop district of Chicago would take so much traffic off the streets that they would have ample capacity for many years to come. Otherwise, the streets soon will have to be increased at enormous costs." The same may be said of New York and many other cities.

The best place for the biway has been considered to be under the sidewalks, but there are many places in which this is impracticable. Several engineers have suggested an elevated biway system, which makes one wonder whether it might not be better after all to put it above the sidewalk. It would have to be fully enclosed, but it would be much lighter and could be made an ornamental structure instead of the intolerably noisy and ugly structures of the present elevated railways. It could be carried easily on a single row of posts along the curb. It would be very quiet in operation and would cost only a fraction of what the subterranean biway would cost. It would have great advantages in crossing streets and rivers and would not interfere with sewers, gas and water pipes, or cables. It would, of course, obstruct the view from second or third story windows, but even that would not be an unmitigated disadvantage.

Finally, consider the possibilities of introducing such a system of transit. Brahdy is quite right in his statement of the difficulties standing in its way, but just as it was possible to build subways that were opposed so strenuously 35 years ago, it should be possible to secure at least a test of a system that offers as much promise for relieving the traffic situation as does the biway. It must be demonstrated before even a small commercial installation can be made. It differs from such things as moving stairways, which are the product of a single factory. So many features are involved that no one manufacturer could undertake it, and as stated in the paper, it can be financed only by some public utility or by the municipality itself. It seems that the cheapest and probably the best place to try out a short installation of this would be in the service between Grand Central Station and Times Square in New York, which is now handled by the shuttle service. This was seriously considered by the authorities at the time Putnam demonstrated his moving platform 10 or 15 years ago. A biway loop under 42nd Street extending from one river to the other would be a very good place to try it, and it is needed badly.

Locomotive to Caboose Radio Communication

Discussion and author's closure of a paper by S. G. Ellis published in the January 1936 issue, pages 109–13, and presented for oral discussion at the transportation session of the winter convention, New York, N. Y., January 30, 1936.

W. H. Arkenburgh (General Electric Co., Schenectady, N. Y.): S. G. Ellis' paper has interested the writer very much, for it describes a development parallel to one carried on by the company with which the writer is connected for the same purpose, namely, to communicate from the front to the rear of freight trains. A brief description of this system appears in the writer's discussion of a previous paper (A.I.E.E. Trans., v. 52, March 1933, p. 294).

The system has been improved since that time, and has produced some excellent results in actual service.

The writer never has done anything along this line in the field of ultra-high frequency radio, because of the uncertainties of the licensing situation and the uncertainties of interference; therefore, a system working on an entirely different principle has received a great deal of attention.

With this system complete privacy is assured, because there is no radio receiving set that could possibly pick up a conversation carried on with this system.

Briefly, inductor coils similar to those used in train control are provided to induce in the rails oscillations corresponding to the modulated carrier, and these oscillations are detected by similar coils either on the other end of the train, on another train, or at some fixed point along the railroad.

In order to make the system efficient, the rails are connected through loading capacitors to any wire that runs along the railroad. The result is that the system is exclusive, and the attenuation and velocity of propagation may be controlled.

One of the problems the writer should like to understand a little better is the reason for different results when the train is at rest and when it is in motion.

D. G. Little (nonmember*; Westinghouse Elec. and Mfg. Co., Chicopee Falls, Mass.): W. H. Arkenburgh's comments are most interesting, particularly his statement that with the carrier current system variable transmission effects are noticed when the train is in motion. With the ultra high

* Closure written by D. G. Little because of S. G. Ellis's death in January 1936. (See Electrical Engineering for March 1936, page 316.)

frequency system described in the paper, the received signal variations that occur are readily explained by the presence of structures along the right of way, such as buildings, power and signal wires, bridges, and other trains, which absorb or reflect the radio waves in a variable manner as the train moves past these structures. However, with the radio equipment described in the paper, these effects have been reduced to a negligible amount and become troublesome at only extreme distances beyond the normal working range of the equipment.

In regard to the licensing situation, the Federal Communications Commission is studying the problem actively. Many temporary licenses have been granted for operation in the ultra-high frequency bands, and it is believed that the advantages of ultra-high frequency radio for railway train communication will result in permanent allocation of certain ultra-high frequency bands for this service.

The carrier current system is, for the present, more private than ultra-high frequency radio; however, for the railway service, it is believed that privacy is generally of minor importance, particularly if the relative economy of first cost and operation of the ultra-high frequency radio system is considered.

Two Methods of Mapping Flux Lines

Discussion and author's closure of a paper by Frank W. Godsey, Jr., published in the October 1935 issue, pages 1032–36, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co.): Field problems are encountered in research and engineering, and 3 possible avenues of approach to their solution are available: experimental study, mathematical analysis, and graphical plotting.

Experimental methods require the preparation of models, a careful arrangement of the apparatus, and carrying out accurately the experimental work. These methods apparently are capable of giving an exact solution, but in practice difficulties such as those described by the author arise.

The experimental method described by F. W. Godsey, Jr. requires 2 sets of models and 2 sets of measurements to establish fully a complete plot of the flux and the equipotential lines. However, it can be said that these 2 measurements check each other. The author has barely touched on 3 dimensional fields. It would have been more convincing if he had extended the simple and interesting 2 dimensional field he has investigated to a 3 dimensional case.

Mostly because of the difficulties involved with the mathematical analysis and also the limitations encountered with experimental methods, the graphical analysis has been developed with the aim to meet a specific need and to a point at which it is now capable of giving good practical results. Whether the field plot be 2 dimensional or 3 dimensional, whether it involve a single medium or many media (dielectrics), in essence the graphical method consists of dividing up the field so that the elements of volume intersected by the flux tubes and the equipotential surfaces all will be of the same elastance (dielectric fields). A certain technique has been built up, and following this technique, assuming a certain aptitude in field plotting on the part of the investigator, it has been possible to solve even difficult field problems. Articles on electrostatic field analysis by M. G. Leonard published in the *Electric Journal* for December 1934 and January 1935 emphasize the extent to which field plotting can be facilitated by following an established technique.

Voltage stresses in high voltage apparatus were investigated by means of field plots by the writer a few years ago with the assistance of M. G. Leonard. The mathematical solution of these problems was out of the question. A few illustrations will be of interest here. A practical problem in which field plots were employed may be found in the discussion of a previous paper (H. V. Putnam discussion, A.I.E.E. TRANS., v. 51, Sept. 1932, p. 595–600). The plot of figure 27 of the discussion just referred to gives the voltage distribution throughout the insulation and the windings of a high voltage shell type, power transformer. The actual voltage stresses were investigated experimentally in the transformer, and the comparison between the calculated and the experimental values are given in figure 28 of that discussion. The agreement is amply good.

Each of the 3 methods, that is, experimental, mathematical, and graphical, has its own usefulness. The nature of the problem generally will determine which of the 3 methods will suit the purpose best.

J. F. H. Douglas (Marquette University, Milwaukee, Wis.): This paper is to be especially commended for the ingenuity and care in the development of a new and valuable method, and for the further light on the problem of air gap induction. The results are even better than those of Hele-Shaw Hay and Powell (*Electrician*, v. 54, Nov. 25, 1904, p 213 and Phil. Trans. Roy Soc., v. 195, 1900, pt. *A*, p. 303–27), good as these were, because equipotentials are shown, and the junction between the 2 media theoretically is more correct.

From the theoretical side, the author has attained one of the 3 latent possibilities in the equation for conjugate fields in thin laminae. If U is flux function, V a potential function, t thickness, and μ permeability of medium, all functions of x and y,

$$\text{curl} = \frac{d}{dx}\left(\frac{1}{t\mu}\frac{dU}{dx}\right) + \frac{d}{dy}\left(\frac{1}{t\mu}\frac{dU}{dy}\right) \qquad (1)$$

$$\text{div.} = \frac{d}{dx}\left(\mu t\frac{dV}{dx}\right) + \frac{d}{dx}\left(\mu t\frac{dV}{dx}\right) \qquad (2)$$

In the field discussed by F. W. Godsey, Jr., curl and divergence are zero, and the thickness is uniform. To secure conjugate fields, therefore materials of conductivity in inverse ratio of permeabilities are used, and equipotentials and flux lines on the boundary are interchanged. Mullner ("Deliniation of Magnetic Leakage Field by Electrical Means," *E.T.Z.*, v. 50, Sept. 12, 1929, p. 1321) secure the conjugate of a vortical field by relacing divergence by curl. The third possibility, has not been tried.

One method of simulating progressive saturation suggested by the equations, is to vary the thickness of the lamina representing the iron regions.

The writer has used conducting paint in experiments similar to those of the author with good results. In an effort to secure a color contrast, he has found only one substance besides graphite that will work. He has found that the kind of graphite and kind of wax make considerable difference in specific resistance of mixture. The writer believes that an improvement in Mullner's experiments might be made by leading current into the brass sheets in the vortical regions through lamina of wax graphite mixture pressed between the brass sheet and a heavy copper plate.

There are many problems of both practical and theoretical interest awaiting the use of Godsey's method, and it is hoped that many will be attracted to these problems as research projects.

F. W. Godsey, Jr.: The examples given by P. L. Bellaschi show the method of curvilinear squares developed to a very high degree in the plotting of flux lines. These examples are accurate and quite useful; however, it is readily apparent that an equally high degree of skill is necessary in so constructing flux maps. For persons with a great deal of practical experience in plotting flux maps, the graphical methods are not too inaccurate. For relatively inexperienced persons, and there are a great many of them, experimental models are the only means of obtaining comparatively accurate results.

J. F. H. Douglas' suggestions as to a means of amplifying the methods outlined in the paper are quite interesting. One of the principle advantages in going to variations in thickness of the model as suggested by Douglas would be the utilization of wedge-shaped models in order to obtain flux distribution in concentrically uniform designs.

A Generalized Infinite Integral Theorem

Discussion and author's closure of a paper by Michel G. Malti published in the November 1935 issue, pages 1222–27, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

H. W. Anderson (Iowa State College, Ames.): M. G. Malti has codified and clearly stated recent advances in providing direct mathematical derivations of certain theorems of operational calculus. Being of a direct sort, these derivations immediately have shown the manner in which generalizations may be made. Carson's infinite integral theorem has been shown to be but a special case of a more general relation that may be used to check the correctness of the solution for an electromotive force represented by almost any sort of time func-

tion, applied to a network with any initial conditions.

The worker who has shown the way for much of this direct approach is van der Pol (the fourth reference of the paper). An appropriate comment that might be taken from van der Pol's paper is that the added terms of this general solution show the individual effects of each initial condition.

Another paper by van der Pol, which might well be mentioned in this connection is: "On the Operational Solution of Linear Differential Equations and an Investigation of the Properties of these Solutions," *Phil. Mag.*, v. 8, ser. 7, June 1929, p. 861–98.

M. F. Gardner (Massachusetts Institute of Technology, Cambridge): Where M. G. Malti multiplies the terms of the differential equation by the exponential ϵ^{-ut} and integrates with respect to t from 0 to ∞, he is in fact transforming the terms of this equation by means of the well known direct Laplacian transformation (L transformation). His restriction of u in the exponential kernel ϵ^{-ut} of this transformation to complex numbers with positive real parts in some cases is too strong. The only essential restriction on u is that its real part shall be greater than the abscissa of absolute convergence σ_a of the integral defining the direct L transformation

$$\int_0^\infty f(t)\epsilon^{-ut}\,dt = F(u) \qquad \begin{matrix}\sigma_a < R(u)\\ u = \sigma + j\omega\end{matrix} \quad (1)$$

The abscissa of absolute convergence of this integral may be defined as the greatest lower bound σ_a of the values which the real number σ may be given and have

$$\lim_{T\to\infty}\int_0^T \left|\epsilon^{-\sigma t}f(t)\right| dt < \infty \qquad (2)$$

For example, if the function $f(t)$ is itself an exponentially decreasing function, σ may be negative, subject only to the requirement that the product function $\epsilon^{-\sigma t}f(t)$ must satisfy equation 2 of this discussion.

The inverse transformation Malti uses for inverting the function $F(u)$ is of the form

$$\frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} F(u)\epsilon^{tu}\,du = \begin{cases}0 & t < 0\\ f(t) & 0 < t\end{cases} \quad (3)$$

This is the well known inverse Laplacian transformation (L^{-1} transformation). The author's restriction of b in the limits of this integral to a positive real number also is too strong in some cases. The only essential restriction on b is that it be a real constant greater than the σ_a defined above.

The use of L and L^{-1} transformations, singly and together, for the solution of linear differential equations with constant coefficients is very old. For example, see the papers of Laplace,[1] Cauchy,[2] Abel,[3] Giorgi,[4,5] Bromwich,[6] Wagner,[7] Carson,[8] Jeffreys,[9] von Stachó,[10] Doetsch,[11,12] and van der Pol,[13] to name only a few. A study of their papers affords ample evidence that the application of these transformations to general disturbing forces and repeated roots is far from new. Even the case of arbitrary initial conditions, as treated by von Stachó, Doetsch, and van der Pol, has been in the literature for more than 10 years.

The section of the paper on extension to nonindicial circuits is an application of the well known theorem for the transform of an nth derivative. This theorem was given by Doetsch,[14] and was used in generalizing the Heaviside type of operational calculus by von Stachó in 1927. By application of this theorem, the transformation of the derivatives in the differential equation involves the necessary initial conditions.

Malti's inverse transformation (equation 7*d*) is not true in general, since $\Gamma(1-m) = (-m)!$ only if m is an integer less than $+1$.

He ascribes the integral expressing the principle of superposition to Duhamel (1833). It will be found 6 years earlier in a paper by Poisson.[15]

The transform for the response, such as the current due to an applied electromotive force, can be divided into 2 factors, one coming from the network or system, which may be called the system transform, and one from the electromotive force or disturbing force, which may be called the disturbing force transform. Malti is mistaken regarding the absence in the literature of any treatment of the problem of finding the system transform when the disturbing force and the response are the known quantities. See the papers of Giorgi. Furthermore, the entire treatment of the synthesis of electric networks, as exemplified by the works of Foster, Cauer, Bartlett, Fry, Brune, and Bode, is based upon an approximation of the system transform, which in turn is but the ratio of a response transform and a disturbing force transform.

To carry out the operations indicated in equation 18*b* of the paper, it is necessary to find the inverse of a transform that is the product of the system and the disturbing force transforms. Now lumped parameter networks have system transforms that are algebraic rational proper fractions; furthermore, disturbing forces (and these include exponential functions) whose transforms are of this type, when applied to such networks give rise to transforms also of this type. The general problem, then, is the inversion of an algebraic rational proper fraction. Malti presents his solution of special cases of equation 18*b* just referred to as an extension of the partial fraction expansion theorem to exponential disturbing forces and repeated roots, and utilizes 4 separate forms. This is not a new solution of this old problem. It has been treated many times before, as mentioned in the foregoing discussion. In contrast to Malti's solution, a solution of the even more general problem cited can be given by a single form. This is done by expressing the solution as the sum of the residues of the integrand of Malti's equation 18*b* at its poles.

The writer is appreciative of the help given by J. L. Barnes, of the Department of Mathematics, Tufts College.

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J. J. Smith (General Electric Co., Schenectady, N. Y.): This paper is an addition to a number of papers that have appeared in recent years on the subject of the Heaviside operational calculus. These are serving the useful purpose of examining the Heaviside method from different points of view, and help to understand it better and deduce new results.

Equation 1*a* seems somewhat restricted as a starting point for the work in this paper. For instance, it would not apply to a circuit consisting of a resistor and capacitor in series. In this case the differential equation is

$$(pCR + 1)i = p\,C\,e\,\mathbf{1}$$

and with this type of equation the assumption made by the author that "$i(t)$ and all its derivatives except the nth are zero when $t = 0$" does not hold. The writer would suggest clarification of the procedure in this case. One way, of course, would be to solve the equation

$$(pCr + 1)y = e\,\mathbf{1}$$

subject to the above assumption with regard to $i(t)$ and its derivatives and then use the relation

$$pCy = i$$

Many authors have used the form of equation $(1-a)$ and the assumption that $i(t)$ and all its derivatives except the nth are zero when $t = 0$ to derive the Heaviside expansion theorem. The latter, as stated in the paper, is based upon the fact that the circuit initially is at rest so that i and all its derivatives are zero before $t = 0$ at

which instant an electromotive force is applied. It is not difficult to show from the Heaviside operational solution that Malti's assumption with regard to $i(t)$ and its derivatives when $t = 0$ is correct in certain cases. To prove it in this manner, however, would be meaningless. The writer should like very much for Malti to explain whether there are any physical reasons that would lead the reader to make this assumption as the equivalent of the conditions under which the Heaviside expansion theorem applies in such cases.

Many of the applications in which the Heaviside expansion theorem shows the greatest usefulness involve continuous systems. A typical operational solution for a transmission line of length l might be written

$$v = \frac{E \sinh \alpha x}{\sinh \alpha l} \mathbf{1}$$

where $\alpha^2 = \partial^2/\partial t^2$. In this case the corresponding differential equation is of infinite order. An indication of how the method in the paper might be applied to differential equations of infinite order and what terminal conditions should be used would be of interest.

The author states in the opening paragraph that Heaviside's operational methods are restricted to circuits that 1 are energized by a continuous electromotive force and 2 are started from rest and have neither charge nor current. The third restriction will not be considered, since the author does not discuss it. Whether these restrictions are a disadvantage or not is open to question. There are 2 ways of proceeding. One is to have several expansion theorems to cover the different restrictions, which is the method advocated by Malti in this paper; the other is to have only one expansion theorem so far as possible and find other means for using this, subject to the restrictions to give a solution in the cases where they do not apply. The latter method has been followed by several authors.

The first restriction may be removed by the use of Duhamel's theorem, mentioned by the author, which is a very useful procedure. There is, however, another well known method. Assume the current in a given circuit operational solution for a continuous applied electromotive force is given by

$$i = \frac{Y(p)}{Z(p)} \mathbf{1}$$

Then for an applied electromotive force $e^{-\alpha t}\mathbf{1}$ the operational solution is

$$i_1 = \frac{Y(p)}{Z(p)} e^{-\alpha t} \mathbf{1} = \frac{pY(p)}{(p+\alpha)Z(p)} \mathbf{1}$$

on replacing $e^{-\alpha t}$ by its operational expression $\frac{p}{p+\alpha}\mathbf{1}$. This operational expression for i_1 can be evaluated by the Heaviside theorem in the usual manner. This method avoids the necessity of using several different types of expansion theorems, which seems to be an advantage. Operational expressions for various types of functions that might be used for different impressed electromotive forces have been tabulated by many authors, and thus their determination presents little difficulty. Examples of the application of this method will be found in the author's references number 3 (chapter 6) and number 6 (page 14).

The second restriction with reference to arbitrary initial conditions may be removed by a method given in chapter 1 of reference number 6 listed by the author. Examples will be found there. This method has also been indicated in the Acts of the International Mathematical Congress 1928, v. 6, p. 327. The procedure is to modify the operational solution in a manner analogous to the previous example and the result is thus obtained by applying the Heaviside expansion theorem in the usual manner.

Joseph Slepian (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): This interesting paper mentions the use of the generalized infinite integral theorem for determining the unknown impedance operator of a system when its complete response to a particular impressed electric force is known. This problem is encountered in practice less frequently than its inverse, but an interesting case arose some years ago, in which cathode ray oscillograms of surge voltage and current at a point in a transmission line were found to be such that the usual approximation of regarding the line as having an impedance operator equal to a constant, $\sqrt{L/C}$ could not be applied. The problem of calculating the impedance operator from the oscillograms then presented itself.

The problem was solved by the use of the generalized infinite integral theorem (discussion, O. Ackermann, A.I.E.E. TRANS., v. 49, July, 1930, p. 933). The theorem was derived from Carson's integral, and it may be of interest to present the derivation here. Carson's integral equation is

$$\frac{1}{pZ(p)} = \int_0^\infty e^{-p\lambda} A(\lambda) d\lambda \tag{1}$$

where $A(t)$ is the indicial admittance. One form of the superposition theorem is

$$i(t) = \frac{d}{dt}\int_0^t A(t-\lambda) e(\lambda) d\lambda \tag{2}$$

Thence

$$\int_0^\infty i(t)\epsilon^{-pt}\,dt = \left[\epsilon^{-pt}\int_0^t A(t-\lambda) e(\lambda)d\lambda\right]_{t=0}^{t=\infty} + p\int_0^\infty \epsilon^{-pt}\int_0^t A(t-\lambda) e(\lambda)d\lambda dt \tag{3}$$

$$= p\int_0^\infty e(\lambda)\int_\lambda^\infty e^{-pt}A(t-\lambda)dt d\lambda \tag{4}$$

$$= p\int_0^\infty e(\lambda)\epsilon^{-p\lambda}\int_0^\infty \epsilon^{-pu} A(\mu) du d\lambda \tag{5}$$

$$= \frac{1}{Z(p)}\int_0^\infty e(\lambda)\epsilon^{-p\lambda} d\lambda \tag{6}$$

Equation 3 of this discussion is obtained from equation 2 by multiplying by ϵ^{-pt} and integrating by parts. The bracketed term of equation 3 drops out and reversing the order of integration of the remaining term gives equation 4. Change of variable $u = t - \lambda$ gives equation 5 and use of equation 1 gives equation 6.

Ernst Weber (Polytechnic Institute of Brooklyn, N. Y.): In this paper, M. G. Malti advances extravagant claims as to the originality of his derivations. A number of references can readily be quoted showing that essentially the same subject has been delivered several times in the past.

When Malti, in his introduction, states "these extensions, however," (as to partial quality and coincidence of roots in the expansion theorem) "have been known only for the case where the applied electromotive force is continuous," the writer needs only refer to the extensive treatment by Mochinoir Goto,[1] in which even other cases are treated in addition to those given by Malti for the case of exponential electromotive forces; this reference is quoted also in reference 2 of the paper.[2] It thus appears that equations 28, 30, 32a, and 35 of the paper are the same, respectively, as the first equation (unnumbered), and equations 30, 25, and 29 of Goto's paper, except that Malti considers several multiple roots and therefore has to employ an additional summation sign.

For Malti's statement "in other words, no theorem has been given which applies to the exponential or the sine electromotive force," the writer needs only refer to Bush's book[2] quoted by Malti, and many of the references given on page 89 of this book, among which is that of J. R. Carson.[3] A derivation of the expansion theorem for applied exponential or sine electromotive forces can also be found in a textbook by Louis Cohen,[4] especially equation 19 of the book; also in the book by H. Jeffreys,[5] quoted by Malti, the formula for exponential electromotive force as equation 11, the characteristic short expression of a mathematician. It thus appears that equations 7 and 19b of Malti's paper are identical with equation 376 (p. 176) of Bush's book,[2] and equation 37 of the paper is slightly less convenient form than equation 20 or 22 (p. 20) of Cohen's book[4] and equation 168 (p. 98) of Bush's book.[2]

There remain the formal solutions of the so-called nonindicial circuits given in equations 17b and 18b, of the paper, but a complete treatment of the nonindicial circuits may be found in the first section of Jeffreys' book,[5] and in a paper by A. Kneschke.[6] Incidentally, equation 14 of Kneschke's paper is identical with equation 23b of Malti's paper.

Since it does not seem possible to establish the originality claimed in the paper, one might still claim a certain systematization of all the so-called forms of the expansion theorem but then the writer should claim that the formulas given are too formal and will not appeal to any practical engineer. For 4 years the writer has used in his own lectures simplified expressions of the expansion theorem (and of all the so-called various types of the expansion theorem with all special cases) in a form that is very readily applied to practical circuits.

It is well known that capacitive circuits contain integrals of the currents, which means negative powers of the operator p. Therefore, equation 1a is not the most general case unless $e(t)$ involves various terms and is not the applied voltage. Finally, it is not true that the minor Δ_{ks} is always a lower degree in the operator p than the determinant Δ. There are possible cases treated in the literature where

the minor has the same degree as the determinant, (see Goto's paper[1]) or the numerator polynomial can be of even one degree higher than the denominator polynomial leading to the "impulse function" extensively treated in the book by Bush.[2]

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M. G. Malti: Before submitting a reply to the various discussions, the author wishes to say that he is extremely gratified that this paper has aroused so much interest and discussion. The personal letters received regarding it show that electrical engineers, whether they be engaged in utility work, manufacturing, or communications, are intensely interested in operational analysis.

The author wishes to thank H. W. Anderson for his statements regarding the paper.

As stated in the introduction to the paper, the form of the generalized infinite integral theorem (equation 6 of the paper) is well known. In fact, it can be readily derived much more simply than Slepian indicates by merely substituting equation 55 in equation 56 (page 48 of Carson's book "Electric Circuit Theory and Operational Calculus"). Slepian's mode of derivation is, nevertheless, interesting.

J. J. Smith concludes that equation 1*a* is restricted because it comprises no negative powers of p and hence does not apply to the series circuit with R and C of which the equation is of the form

$$iR + (1/Cp)i = e(t) \qquad (1'a)$$

or

$$[R + (1/C)p^{-1}]i = e(t) \qquad (1'b)$$

Now the whole theory of the paper applies to the case under consideration with no modification whatever. In order to prove this statement in the most general case let an integro-differential equation be

$$[a_n p^n + a_{n-1}p^{n-1} + \ldots + a_0 + a_{-1}p^{-1} + a_{-2}p^{-2} + \ldots + a_{-m}p^{-m}]i(t) = e(t) \qquad (2')$$

Let

$$p^{-m}i(t) = f(t) \qquad (3')$$

Substituting (3′) in (2′) we have

$$[a_n p^{(n+m)} + a_{n-1}p^{(n+m-1)} + \ldots + a_0 p^m + a_{-1}p^{m-1} + \ldots + a_{-m}]f(t) = e(t) \qquad (4')$$

Equation 4′ is of the same form as equation 1*a* of the paper. Hence, any integro-differential equation of the form of equation 2′ (which includes equation 1′ as a special case) can be readily reduced to the differential equation 1*a* of the paper. It must be observed, however, that the initial conditions are given for $i(t)$ and not for $f(t)$. To change these initial conditions to initial conditions involving $f(t)$ it is necessary simply to recall that by definition

$$p^{-k}\, i(t) = \int_0^t p^{-(k-1)}\, i(t)dt \text{ for } k = 1, 2, \ldots\, m \qquad (5'a)$$

Hence

$$p^{-k}\, i(t)\Big|_{t=0} = 0 \text{ or } f^{(m-k)}\,(0) = 0. \qquad (5'b)$$

From this it is observed that

$$f(0) = f'(0) = f''(0) \ldots = f^{(m-1)}(0) = 0 \qquad (6'a)$$

$$f^m(0) = i(0), f^{(m+1)}(0) = i'(0), \ldots, f^{(m+n-1)}(0) = i^{(n-1)}\,(0) \qquad (6'b)$$

The case of a system of differential equations is similarly treated by applying equation 3′ to the lowest order of $i_r(t)$. Thus let Z_{rs} in equation 8 of the paper be the impedance that contains the lowest negative power of p among all the Z_{rk}. Let that power be p^{-m}. Then from equation 3′

$$p^{-m}i_r(t) = f_r(t) \qquad (7')$$

The set of integro-differential equations are then reduced to a set of differential equations in $f_r(t)$.

Smith raises a further question regarding the initial conditions. The paper gives 4 infinite integral theorems and their transforms as follows:

1. Equations 6*b* and 7 apply to one differential equation with indicial boundary conditions, that is, $i(0) = i'(0) = \ldots = i^{(n-1)}(0) = 0$.

2. Equations 10 and 12 apply to a system of differential equations with indicial boundary conditions.

3. Equations 16*b* and 17 apply to one differential equation with nonindicial boundary conditions.

4. Equations 18*a* and 18*b* apply to a system of differential equations with nonindicial boundary conditions.

In this way all possible initial conditions of linear differential or integro-differential equations with constant coefficients are covered.

Regarding the multiplicity of expansion theorems, it may be stated that equations 16*b* and 18*a* of the paper are the only 2 expansion theorems necessary. The first is for one differential equation and the second for a system of differential equations. Equations 6*b* and 10 of the paper are obviously special cases of 16*b* and 18*a*.

The third question relates to transmission line equations and other partial differential equations. That such equations can be directly and beautifully solved by the methods of this paper has been very ably demonstrated by Doetsch in a series of papers given in references 1 to 10 at the end of this discussion.

The writer is familiar with the purely operational methods referred to by J. J. Smith and has been led to the transform method given in this paper because purely operational methods suffer from at least one defect. They are "slippery"—one never can be sure of his ground. There are certain rules-of-thumb that are known to work, but why they work and when they cease to work are questions answered by transform methods.

The author would have Ernst Weber understand that he has advanced no claims (extravagant or otherwise) in the printed or the oral presentation of the paper. Any person familiar with the subject knows what is new in the paper and what is not new.

Weber's reference to Goto's work does not refute the author's assertion that the extensions have been known only for the case in which the applied electromotive force is continuous. Goto's derivations for sine and exponential functions (which are continuous) have nothing to do with the case of discontinuous functions for which the transforms equations 17 and 18*b* of the paper hold.

Weber admits that equations 28, 30, 32*a* and 35 of the paper contain an extra summation sign over and above Goto's equations. That extra summation sign physically represents additional cases of electric circuits than can be solved by this method and completes the total number of possible cases that could be encountered. Weber need not be reminded that any treatment that does not cover all possible cases is mathematically and physically incomplete.

In referring to works of Carson, Bush, Cohen, and Jeffreys, Weber seems not to realize the difference between restricted circuits wherein all the roots are unequal and a circuit wherein the roots of the operational equation may assume any value. The references he gives (Bush, Carson, Cohen, and Jeffreys) all deal with the most elementary case of unequal roots. The paper under discussion deals with unequal, equal, and repeated roots and hence constitutes an extension of modern knowledge of operational and transform methods as applied to circuit problems.

As to the identity of equations 7 or 19*b* of the paper with Bush's equation 386, Weber might be interested to note that no originality is claimed in this paper for transform methods that have been known since Laplace's time.

Weber calls attention to equation 37 of the paper and states that it is slightly less convenient than equations 20 and 22 (p. 20 of Cohen's book). For Weber's information the author might state that equation 37 of the paper and Cohen's equations 20 and 22 refer to entirely different circuits. Equation 37 of the paper applies to the current in any branch of a mesh containing several sine electromotive forces while Cohen's equations apply to a singly excited circuit. Equation 37 of the paper is, therefore, much more general than Cohen's. Weber's confusion in this matter might account for his assertion that equation 37 of the paper is in a slightly less convenient form than Cohen's.

Weber's references to Jeffries's and Kneschke's works relative to equations 17*b* and 18*b* of the paper are misleading. While Jeffries treats the nonindicial case, his results (see p. 9–12) are not of the same form as equation 17*b* and 18*b* of the paper. Jeffries's equation 15 is of the same form as equation 18*b* of the paper, but Jeffries's equation is restricted to the unit function

only while equation 18b applies to any function. As to Kneschke, his treatment, while using the transform method, does not cover the nonindicial case of equation 18b; moreover, Kneschke treats the case of a system wherein $Z_{ks}(u)$ is of the second degree only. The treatment of the paper is not so restricted (see equation 8).

It is surprising that Weber does find originality in the systematization of all infinite integral theorems, but he hastens to state that the formulas are too formal for the practical engineer. This charge is immediately refuted by the direct applications of the formulas in the paper to the various cases arising in practice (see section on application to exponential electromotive forces).

Weber's statement that equation 1a of the paper is not the most general case, unless $e(t)$ involves various terms and is not the applied voltage, is untrue.

M. F. Gardner's question about the severity of the condition on $R(u)$ is of mathematical interest. Although the condition $R(u) > 0$, $b > 0$ is in some cases a bit strong, yet it is much more clearly understood by the average engineer than the restriction that "$R(u)$ shall be greater than the abscissa of absolute convergence"; moreover, the restriction placed on b is of little significance so far as the actual evaluation of the transform is concerned. Indeed, in all practical cases considered in the paper, the author has encountered no difficulty due to this restriction.

Gardner gives some very interesting ancient history regarding the use of L and L^{-1} transformations by mathematicians. Unfortunately the author does not access to Laplace's volume 10, but upon looking up the other and later references quoted by Gardner it is discovered that

1. Cauchy derives some properties of the Fourier integral. His work (see Gardner's reference 2) has nothing to do with the paper.

2. Abel studies Laplace's transform and some of its properties and actually derives "Heaviside's shifting." Abel, however, does not apply Laplace's transform to the solution of differential equations and hence his work is remote from the subject matter of the paper.

3. Giorgi (in the International Congress, Toronto, 1924) used the Fourier integral in a form similar to equation 7 of the paper, but not in connection with circuits. Giorgi also justifies some of Heaviside's work by transform methods. He further derives Heaviside's expansion theorem, but not through transform methods. He has nothing in his paper on equal or repeated roots, and does not treat systems of differential equations.

4. Bromwich gives an interpretation of certain operational expressions by means of the transform.

5. Wagner uses the transform in order to prove Heaviside's expansion theorem for the case of unequal and repeated roots, but for indicial conditions only.

6. Carson has the infinite integral theorem, but he does not use the transform at all; moreover, he obtains the case of arbitrary electromotive forces from the case of a constant electromotive force by the superposition theorem.

7. Jeffries' work is summarized in the foregoing answer to Weber's discussion.

8. Von Stacho uses the infinite integral theorem, but not the transform. He mentions very briefly ordinary differential equations. He has no results on systems of differential equations.

9. Doetsch's main interest is in partial differential equations (see references 1 to 10 at the end of this discussion). He has no results for ordinary linear differential equations and systems of such equations, which is the subject of the paper.

10. Van der Pol derives the infinite integral theorem for single differential equations and for systems, but does not use the transform.

The conclusion drawn is that these references form an excellent historical background for the paper. It appears that the results of the paper have not been anticipated by any of these references.

For Gardner's reference to Bush regarding extensions of Heaviside's expansion theorem see the foregoing reply to Weber's discussion. As to Cauchy, this work covers only the case of a single differential equation with unequal roots.

The method of residue suggested by Gardner, relative to the evaluation of the transform is not essentially different from that used by the author. The results of the paper are carried as far as possible for the convenience of the engineer.

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Effect of Total Voltage on Breakdown in Vacuum

Discussion and author's closure of a paper by H. W. Anderson published in the December 1935 issue, pages 1315–20, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

R. C. Mason (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): Although the work of H. W. Anderson extends the knowledge of vacuum breakdown to an entirely new range of voltages, the explanation of all the phenomena involved still is not clear. Below 50 kv a critical gradient at the cathode, presumably that sufficient for cold cathode emission of electrons in considerable quantities, seems essential for breakdown. Recent experiments by the writer show that even when a copious supply of initiatory electrons are present at the cathode, still a constant field of about 5×10^5 volts per centimeter is necessary at the cathode for all electrode separations at least up to those requiring 50 kv for breakdown. Investigations in the past have suggested that high speed electrons might cause positive ion emission from anodes, and it is logical for Anderson to assign this cause for his observed variation of breakdown voltage with separation beyond 50 or 100 kv.

The positive ions freed from the anode might affect the breakdown voltage in either of 2 ways:

1. Indirectly, the positive ions striking the cathode might alter the character of the surface of the cathode, either by depositing anode material upon the cathode or by changing the form of surface irregularities, so as to increase the cold cathode emission. In this way, for a test in which electrode separation and breakdown voltage increased, the applied field necessary to give any particular cold cathode current would decrease. If this explanation is correct, then the surface change should be permanent, so that if the gap length were reduced from its largest value, the field for breakdown would stay constant at the minimum observed value. Anderson mentions that the lower parts of the curves in figure 1 of the paper are shifted somewhat after the data for the upper points are taken. In what direction, and approximately how much, are the lower parts of the curves shifted?

The same remarks apply also to figure 3 of the paper. If positive ion bombardment were causing a change in the cathode surface, then the current flowing for a particular voltage and separation should not be constant, but should change with time of application of voltage. Was such a change observed? For a particular separation, would the same current be measured for a given low voltage before and after the application of a higher voltage?

2. Directly, the positive ions might affect the breakdown voltage by virtue of the electron emission they will cause from the cathode. If the first hypothesis is not correct, then the extremely rapid variation of cold cathode emission with field means that such emission will be entirely negligible for breakdown voltages above, say, from 200 to 300 kv (figure 1). Then breakdown must proceed entirely by the interaction of the positive ion production at the anode by electrons, and the electron production at the cathode by positive ions. Such a process should depend only on the applied voltage, and not upon the electrode separation, so that beyond the point where cold cathode emission fails to be important, the breakdown voltage should be constant. Why, then, does the observed breakdown voltage increase continuously with electrode separation?

From the heating of the electrodes, Anderson concludes that the electron current is several hundred times the positive ion current, yet he says that a 20 minute application of voltage below the breakdown value transferred enough anode material to produce a brownish spot on the cathode. The value of the current in the latter test is not given, but if it were comparable to

the currents plotted in figure 3 of the paper, or say 1 microampere, then the total number of positive ions arriving at the cathode during the test would have been less than 10^{13}—a number far too few to have been seen if they had all remained on the cathode. If the minimum amount of material likely to be noticed by the naked eye is estimated to be a layer 1,000 molecules thick over a 1 millimeter square, then about 1 atom must have been deposited for each electron leaving the cathode, assuming the electron current to be 1 microampere. The deposit of material and the heating experiment are compatible only if most of the material passed from anode to cathode as neutral atoms.

Another way of estimating the positive ions liberated from the anode possibly might be found from figure 3 of the paper. If the effect of the positive ions follows the foregoing second hypothesis, then the current before breakdown will be

$$i = i_0' \frac{1 + \delta}{1 - \gamma\delta}$$

where δ represents the number of positive ions leaving the anode per incident electron, γ is the number of electrons liberated from the cathode per positive ion impact, and i_0 is the cold cathode current from the cathode, or the current arising from a source independent of the total voltage. Both δ and γ are functions of the voltage; for the range covered in figure 3, γ probably lies between 1 and 10. Rough fitting of this equation to the curves shows that r must increase rapidly with V below 40 kv, and change very slowly from 60 to 120 kv. The limiting values of δ would be 1 if $\gamma = 1$, and 0.1 if $\gamma = 10$. It seems unlikely that δ actually is appreciable below 40 kv. It is hoped Anderson will clear up some of the foregoing queries.

H. W. Anderson: R. C. Mason's comment (1), concerning the so-called permanent manner in which positive ions from the anode might affect breakdown voltage, conforms with the experimental work on which the paper is based. As stated in the paper, a copper anode opposite a steel cathode results in characteristics similar to those obtained with both electrodes of copper. The curves of figure 1 of the paper were taken with steel electrodes, and those of figure 3 of the paper with nickel; thus, in each of these cases Mason's comment would be limited to the changing of surface irregularities. Also, such bombardment may be quite effective in cleaning the cathode. During the establishment of voltage across a pair of electrodes, momentary pulses of current often were observed, and were considered to be incidental to the conditioning of the electrode surfaces. After such initial pulses, however, the current usually would become fairly steady. Consequently, additional positive ion bombardment during the time of making the experiments did not seem to cause a change in gap characteristics that could be represented as a function of time.

When the interelectrode voltage was increased to the breakdown value, as was of course repeatedly done for the data of figure of the paper, gap characteristics were changed so that the lower portion of the curve could not be closely checked after taking data for the upper portion. The change, however, varied from time to time both in magnitude and direction. When breakdown voltage (for a given gap length) was increased, the result was attributed to electrode cleaning, or possibly the destruction of emitting points on the cathode. When breakdown voltage was decreased, the formation of sharper cathode irregularities was suspected. However, the resulting curve of breakdown voltage versus gap length still would be quite similar to that of figure 1 of the paper. Thus, the field for breakdown would by no means remain at a constant minimum value corresponding to that of the highest voltage reached.

Since the lower part of the curve of breakdown voltage could not be reproduced after taking the high voltage values, Mason suggests that a similar variation might also apply to the measurements of figure 3 of the paper. It should be noted, however, that the measurements for these 2 figures differ in one very important respect: figure 1 of the paper necessarily was taken with repeated breakdown, whereas breakdown was avoided during the entire run for figure 3 of the paper. The measurements for figure 3 were made after a period of electrode conditioning, which had brought the gap to a stable condition, and the low voltage points could be checked after the application of higher voltage.

Mason states in his second comment that the proposed positive ion hypothesis should lead to a ceiling beyond which breakdown voltage could not pass. The empirical equation for figure 1 of the paper corresponds to just that, but the writer hesitated so to extrapolate. That such extrapolation is a dangerous process is exemplified by the fact that measurements below 50 kv would lead to the conclusion that breakdown occurs at constant gradient.

Mason appropriately questions whether the accumulation of anode material upon the cathode conforms to Faraday's law. The visible spot described occurred with a copper anode and steel cathode, which combination resulted in the gap taking the relatively inferior insulating characteristics of copper electrodes. Thus the interelectrode current was much larger than that of the nickel electrodes of figure 3 of the paper, and was actually about 100 microamperes. Besides this, the estimated depth of 1,000 molecules seems somewhat large. The volume optical properties of a metal are considered to start with a layer about 50 molecules thick. Although these values conform to Faraday's law, it must be admitted that this does not prove the entire absence of a sort of sputtering due to electron bombardment. On the contrary, some form of mutual electrode bombardment is necessary to account for the observations described in the paper.

Mason has brought out the reason why splashing coefficients (suggested by R. J. Van de Graaff, reference 8 of the paper) were not evaluated. The electrode for figure 3 of the paper was changed in characteristics by sparkover. After this occurrence, the electrode produced curves of similar shape, but with different values of current. After considerable work with this electrode, it was decided that a study of splashing coefficients would require an entirely different type of electrode arrangement, utilizing a known beam of electrons kept in a separate track from that of the resulting positive ions by a transverse magnetic field. With suitable provisions for current measurement, splashing coefficients might then be determined.

I.E.C. Adopts MKS System of Units

Discussion and author's closure of a paper by Arthur E. Kennelly published in the December 1935 issue, pages 1373–84, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

J. J. Smith (General Electric Co., Schenectady, N. Y.): In this paper A. E. Kennelley has given a very fine review of the work from 1848 to the present to standardize the electrical units. The third action taken at the latest meeting of the I.E.C. in 1935, and also adopted as the title of this paper, may lead to some slight confusion. It is stated that "The question of adopting the mks system then was moved and unanimously approved, except that 2 countries made reserves as to the suitability of retaining the kilogram as a basic unit of the system." Resolution 1 of the I.P.U. meeting at Chicago states "That the classical cgs system should be left unchanged." It is the writer's understanding that the action in approving the adoption of the mks system by the I.E.C. did not affect the status of the cgs system and he should like reassurance from Kennelly on this point.

In connection with the fourth unit required to make up the mks system, it is stated that the ohm and the coulomb had been suggested. In a recent article in *Nature*, Sir Richard Glazebrook suggests the use of μ for this unit. The writer believes that the adoption of this fourth unit deserves very careful study before a final decision is made. One of the reasons guiding the choice of this unit should be to allow the logical development of a system that could be readily understood by engineers in the future. If the coulomb is adopted, this can be done somewhat along the lines of the present cgs system, in which 2 equal charges placed one centimeter apart and acting upon each other with a force of one dyne, are considered to be unit charges. Of course it suffers from the disadvantage that it is not possible to keep a unit charge stored somewhere like the units of length and mass. This is not so serious as it seems. On the contrary, if the ohm or the permeability should be used as a basis, it appears necessary to base the development of the system on a seemingly empirical basis. It is recognized that they may have advantages from other points of view. The subject is too lengthy to discuss further at this time, but it is one worthy of careful study before taking any final action.

H. L. Curtis (National Bureau of Standards, Washington, D. C.): In A. E. Kennelly's interesting paper he has indicated the historical background that has led to the proposal of including the meter-kilogram-second (mks) system as one of the systems of

units available to engineers. He has also indicated some of the advantages of such a system. The writer wishes to state what seems to be the most important consequence resulting from the use of the mks system, and to present views concerning the usefulness of this system as compared to the cgs system.

The most important consequence that would result if the mks system were to replace the centimeter-gram-second (cgs) system is the necessity of including permeability as a factor in many electrical equations, particularly those that include both electrical and mechanical quantities. In the cgs system, the permeability of every fluid in common use is so near unity that equations frequently are written without including permeability, whereas in the mks system the permeability of every such substance is 10^{-7}. In most problems concerned with conductors surrounded by a fluid, engineers who employ the cgs system usually omit the symbol for permeability, since it does not enter in a numerical calculation; however, in the mks system every equation must contain permeability as a factor, and its value of 10^{-7} must be introduced in computing numerical results. Whether this consequence is an advantage for one system or the other cannot be decided beforehand. The mks system will appeal to some engineers because it requires more precise thinking; to others the cgs system will seem to be simpler.

The writer wishes to discuss the advantages Kennelly claims for the mks system. In the first advantage he lists, he calls attention to the simplification introduced because all conversion factors between the mks and practical systems are unity, whereas in the cgs system various powers of 10 are required. This advantage must be balanced against the disadvantage of having to introduce a numerical value for the permeability. In other words, the remembering of powers of 10 should be contrasted with the necessity of remembering for each application whether permeability is a factor in the numerator or denominator, and whether the first power or the square root must be employed.

The second advantage listed by Kennelly is that the mks system requires no accompanying electrostatic system. This is not discussed in any other part of the paper. It is supposed that electrostatic formulas, such as the one for computing the capacitance of a capacitor from its mechanical dimensions, are intended to contain a function of the velocity of light. However, in this respect it is no different from the cgs electromagnetic system in which all electrical and magnetic quantities can be expressed. The electrostatic system has survived because of its usefulness in certain problems. It is not a necessity in the cgs system.

The third advantage claimed by Kennelly for the mks system is the absence of fractional exponents in dimensional formulas, and he refers to Giorgi's recent publication on the subject. If Giorgi's statements are interpreted correctly by the writer, he has accomplished this simplification by selecting a different physical quantity as one of the fundamental quantities in terms of which the dimensional equations are written. Giorgi states "it does not matter whether we put the fourth fundamental into the permittivity of a dielectric or take the coulomb or the ohm or the volt itself as fundamental, except that the latter course leads to the simpler results." The dimensional equations are entirely independent of systems of units, and depend only on the physical quantities employed as the fundamentals. However, if some quantity other than permeability is chosen as the fundamental, permeability has a dimension and cannot be treated as an abstract number. For example, if current is the fourth quantity, permeability has the dimensions of a force divided by the square of the current, whereas, if inductance is the fourth quantity, permeability has the dimensions of inductance divided by length. It seems that the discussion of dimensional equations might well be entirely separated from the discussion of systems of units.

The writer does not believe that Kennelly considers the last 4 advantages he lists to be of great importance. Hence, instead of discussing them, some of the adjustments in our mental processes that will be required if the mks system is to come into general use may be discussed to advantage. Many of the constants in daily use will have quite different values in the mks system from those with which engineers and physicists are familiar. For example, the permeability of iron, which has values ranging from 1 to 10^5 in the cgs system, would have values from 10^{-7} to 0.01. This is particularly awkward because no name has been given to permeability; consequently, the metric prefixes cannot be applied. Another change that will be troublesome is the new form that must be given to some familiar equations. For instance, the equation connecting the permeability μ of a medium with its susceptibility K, which in the cgs system has the familiar form $\mu = 1 + 4\pi K$ is not applicable in the mks system.

The writer does not see how the mks system can come into general use until its nomenclature is completed and tables of physical constants are prepared in which values are expressed in the mks system. Then, to quote Giorgi, "Future practice will show which units are the most convenient for every particular purpose and the law of the 'survival of the fittest' will receive application."

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): As an engineer, the writer is decidedly in favor of the adoption of the mks system of units for the various reasons given in the paper. With regard to the choice of a fourth unit, it appears that the I.E.C. has limited its consideration to the 7 practical units, namely, coulomb, ampere, volt, ohm, henry, farad, and weber, and that various reasons have been given for the adoption of 1 of the first 4 of these units. This is perfectly natural, for each of these 4 units has certain advantages, depending upon the viewpoint and principal interests of the advocator. There are arguments in favor of the ohm and volt, because they can be used as reference standards in laboratories; the ohm in particular can be used as an international reference standard the same as the meter and kilogram. Many teachers favor the coulomb because it represents the unit quantity of the medium dealt with, and therefore forms a natural basis for teaching the entire system. The ampere is favored by others, because it is directly connected by simple relations, not only with the fundamental basis of the system, but also with other electrical and magnetic magnitudes. The writer believes that under such conflicting circumstances it will be very difficult to make a choice from the 4 favored units.

In contrast to the position taken by the I.E.C., it seems that the Consultative Committee on Electricity, of the International Committee on Weights and Measures, and also the S.U.N. Committee of the International Union of Pure and Applied Physics lean definitely toward the use of permeability (10^{-7} in the unrationalized system, or $4\pi 10^{-7}$ in the rationalized system) as the connecting link. It seems that it would be worth while for the I.E.C. to give this proposal serious consideration, as it not only would avoid any possible conflict between the mks and the cgs systems but also it might facilitate an early agreement among the various international bodies concerned.

W. H. Michener (nonmember; Carnegie Institute of Technology, Pittsburgh, Pa.): The writer's purpose is to encourage co-operation between electrical engineers and physics teachers. It is evident that such co-operation is necessary. Most electrical engineers received their first formal instruction in electricity from their physics teachers and physics teachers must depend on electrical engineers for equipment and instruments, and for the development and application of the principles they try to teach.

There is much disagreement among both physicists and engineers on the subject of units. The adoption of the mks system is a big step in advancement, but there are many details of the system still to be worked out. One important question is that of rationalization, that is, the location of the 4π that must appear in certain equations. It is the belief of the committee on units of The American Association of Physics Teachers that the question should be decided so that both forms of equations would not be in the mks system. Which choice is made is not so important as that a choice be made. The writer should like very much to get the opinion of any electrical engineers who have considered the matter. Electrical engineers apparently use the ampere-turn as a unit of magnetomotive force. Do they wish this to be the only such unit in the mks system, or do they wish a unit of 4π ampere-turns? The numerical work in most problems appears to be identical. If the 4π is avoided in computing H, it still must be used in computing B.

What is taught in elementary physics eventually will be used to a considerable extent by electrical engineers. The prevalence of unrationalized units in electrical engineering practice is due, no doubt, to the fact that they were used almost exclusively in elementary physics texts, but in addition, apparently there has been use for some rationalized units, such as the ampere-turn. Now if a rationalized system is taught, will it be necessary or desirable to introduce any other units? Physics teachers would like to teach the system that would most nearly satisfy all needs. They cannot hope, of course, to include in a system such hybrids

as ohms per foot and maxwells per square inch.

In discussing the influence of physics teaching, the writer should mention one place in which that influence has been detrimental. It is on the subject of fundamental quantities and dimensions. A few faulty statements appearing in physics texts, and handed on from book to book, have caused endless arguments and misunderstandings. The word fundamental perhaps is misleading. The dimensions of a unit are quite arbitrary, and depend on the equations and definitions adopted—not upon any inherent physical nature of the quantity being measured.

H. L. Curtis has mentioned the changes in the numerical value of permeability that will be necessary in the mks system. It seems that there will be need for a relative permeability whose numerical value is the same as the familiar permeability in the cgs electromagnetic system. To find the absolute permeability it is then necessary only to multiply present tabulated values by the constant 10^{-7} or $4\pi\ 10^{-7}$ which may be called the permeability of free space.

C. H. Sharp (consulting engineer, White Plains, N. Y.): The action of the I.E.C. in adopting the Giorgi system has the effect of changing the status of ordinary electrical units from that of derived units of the cgs system to that of primary units in an independent absolute system. Evidently the meter, kilogram, and second make just as logical a basis for a system of mechanical units as do the centimeter, gram, and second. By making a proper association, our ordinary electrical units become a part of that system. Such an association was required in the cgs system, and for the purpose of binding a particular system of electrical units to the cgs system, the permeability of free space was assumed to be unity. A similar association could be effected in the mks system by taking the value of 10^{-7} for this quantity, and this would seem to be a logical procedure. Alternatively, one of the electrical units could be designated as a basic unit, and the effect would be the same.

The relative convenience or inconvenience of a rationalized, as compared with an unrationalized system of magnetic units, seems to depend somewhat on the particular field of work in which they are to be used. Historically our present system was built from the point of view of the magnetist, to whom the unit magnetic pole was the starting point in establishing a system of units. A magnet pole of unit strength was defined readily a pole that would exert a unit force on an equal pole placed at a unit distance from it. When the concept of magnetic flux became of practical importance, and a unit of flux was required, it was optional to choose as such unit either the total flux from a unit pole or the flux through a unit solid angle from such pole. Actually the unit of flux was defined as the flux through a field of unit strength and unit area. This is equivalent to defining it as the flux from a unit pole through a unit solid angle, and as a result the total flux from a unit pole is 4π units.

This was quite satisfactory to the magnetist dealing with unit poles and unit fields, but in electromagnetics the matter is somewhat different, for the magnetic flux is established in another way, namely, by electric currents, and a basis different from the ficticious unit pole is found on which the definition of the unit of flux can be set up. Flux is now the fundamental quantity, and the relationship between flux and current that causes it becomes the starting point of the definition. With the present definition of unit flux, 4π appears inconveniently in this relationship, which is the fundamental one in electromagnetic calculations. The rational thing to do is redefine the unit of flux so as to eliminate 4π from the fundamental relationship. The result is the same as if the total flux from a unit pole were taken as the unit. The troublesome 4π is not abolished, but is removed from the places in which it is most objectionable. Whether this change should be made evidently is a question that should be answered by those having the greatest practical interest in it.

It is interesting to consider the somewhat analogous system of photometric units. In this system the unit point source of light is the only practical starting point, and the unit of luminous flux must be derived from it. As before, this unit might be taken as the entire flux from a unit point source or the flux from such a source in a unit solid angle. The latter is by far the more advantageous choice. It allows illumination to be expressed and computed either in terms of candle power divided by the square of the distance, or as the lumens per unit area. The 4π constant is taken care of in the standardizing laboratory by standardizing lamps in terms of either lumens or candle power; nevertheless, some multiple of π crops out in other less important places, as in the computation of the luminous flux from extended sources.

C. L. Dawes (Harvard University, Cambridge Mass.): In this paper A. E. Kennelly describes the mks system of units on which the International Electrotechnical Commission finally has reached unanimous agreement. In general the system is the usual practical system heretofore derived from the cgs electromagnetic system by changing the unit of length to 10^9 centimeters and the unit of mass to 10^{-11} grams. The electrical units themselves in reality are the units of the practical system.

Instead of being an offshoot of the fundamental cgs system, the practical system now becomes an independent one derived fundamentally from the meter, kilogram, and second. So far as the usual practical measurements of electrical quantities are concerned, one scarcely will feel any effect of the adoption of this mks system. In the writer's opinion, it is highly advantageous that a single system now has been adopted as an international standard.

It is pleasing, however, to learn that no attempt is made to abolish the cgs magnetic and electrostatic systems, for it is believed that the respective magnetic and electrostatic units of these 2 systems are far superior to those of the mks system for the development of analytical relationships and for the usual computations in the magnetic and electrostatic circuits. For example, the cgs systems are based on unit poles and unit charges, so that they are not only easy to visualize, but also they are expressed in the simple quantities of the dyne, centimeter, and erg, and the coefficients are π or simple integers. In a number of years of teaching experience, the writer never has experienced any difficulty in teaching students to understand and use these units and convert them to the practical system when necessary. Students visualize very readily the concept of the 4π lines that emanate from the unit pole or unit charge.

In electrostatics, both elementary and advanced, which is the writer's particular field, it is found that the developments of complicated relationships may be accomplished in a very simple and direct manner if the cgs system is used. This simplicity is doubtful if attempts to use the mks system were made.

Another factor that will prolong the lives of the 2 classical cgs systems is that it is difficult to break with a past having such a substantial and extensive development, with the accompanying literature contributed by such outstanding scientists as Faraday, Kelvin, Ewing, Weber, Henry, Maxwell, and others.

The writer is inclined to disagree with the author's advantages 1 and 2, which relate to the elimination of conversion factors and the ease of making electrostatic computations in the mks system. Practically the only conversion factors needed in the ordinary uses of the cgs systems are 10^{-8} in the magnetic system for converting abvolts to practical volts and 9×10^{11} for converting statfarads to farads. Sometimes the factor 300 is used to convert statvolts to practical volts. It is not difficult to remember any of these other factors.

On the contrary, space permittivity in the mks system, instead of being unity for the simple unit cube now is 8.854×10^{-12} or 1.113×10^{-10} depending on whether the system is rationalized or unrationalized. Likewise, reluctivity is 0.7958×10^6 instead of the reluctance of the simple unit cube. None of these factors is easy to remember.

The advantage (3) of eliminating fractional exponents does not appear to be a real one, since in ordinary usage as stated above, one seldom converts any units involving fractional exponents when employing the 2 cgs systems in practical work.

In order to hasten the establishment of the mks system, it appears that either the rationalized system or the unrationalized system should be standardized next. As Kennelly states, at present the disagreements cannot be reconciled, but undoubtedly in the near future the trend toward one or the other may become sufficiently pronounced to swing the minority into agreement. The writer prefers the unrationalized system, for it is more simple to visualize 4π lines emanating from a unit pole or charge in all directions instead of a single line with no determined direction. As to the fourth quantity needed to define the system, the writer is inclined to agree with Campbell that the volt is most desirable, since it is a very tangible quantity. In practical work it is specifically defined and measured in terms of the saturated Weston cell.

For a number of years Kennelly has given much of his time and energy in the interest of standardization of units and nomenclature and the writer believes that all should be grateful to him as the United

States representative for his part in bringing about at last the international standardization of a practical system of electrical units.

A. A. Nims (Newark College of Engineering, Newark, N. J.): A noteworthy feature of A. E. Kennelly's report is the reduction of the fundamental electrical units from 5 to 4. To the fundamental units of length, mass, and time, which are sufficient for computing mechanical energy, there is to be added a fourth unit for the electrical computation, as there is a fourth unit, temperature, for the computation of the thermal energy.

With regard to the selection of the fourth unit for electrical phenomena, it has already been pointed out that there are 3 viewpoints to consider: first, that of the educators, who have to explain the units, both fundamental and derived, and their relationship; second, that of the experimenters who have to prepare, maintain, and compare the material embodiments of the necessary units; and third, that of the designers who have to calculate in terms of these units.

The third viewpoint seems to be in a favored position, for the present proposal is to make the practical units, in which practically all engineering computations are made, fundamental for scientific computations also. Concerning the other 2, it is questionable whether it is essential that the standard units of reference and comparison be those that are fundamental philosophically, or conversely, whether it is necessary that our philosophy of physical units be founded upon the 4 most convenient to produce in material form.

In this connection, it is pertinent to mention that for years the international prototypes have not been the centimeter or the gram, but the meter and the kilogram. Here the ratio between a fundamental unit and its prototype is one of magnitude.

It may not be equally proper for a material standard of reference to be only a physical factor or component of a fundamental unit, but some consideration is due a suggestion recently made to the writer; that is, that a meter-joule-second (mjs) system might be philosophically as fundamental as an mks system, since energy is the one real entity in the physical world. Admittedly it might be somewhat inconvenient to maintain a standard joule for comparison, but its mechanical components already have been standardized.

From this aspect, it would seem that one of the electrical components of energy would be a more appropriate fourth unit than one of the properties of space or matter.

Ernst Weber (Polytechnic Institute of Brooklyn, N. Y.): In table I of the paper the personal names for the mechanical mks units of pressure and force are missing. In a previous paper ("A Proposal to Abolish the Absolute Electrical Unit Systems," Ernst Weber. A.I.E.E. TRANS., v. 51, Sept. 1932, p. 728–42) the writer proposed for the unit joule per meter the name "newton." It seems fitting and proper to employ Newton's name for the fundamental unit of force in the final international system of units. From this fundamental unit would follow the unit of pressure as newton per meter squared and the unit of torque as newton-meter. This would facilitate the use of the mks unit within a gravitational dimension system having as fundamental dimensions length, force, and time. The need for such a dimension system is obvious in all engineering fields, and its use is becoming more and more predominant. The system as a gravitational system then could be suitably called the meter-newton-second (mns) system of units.

Inasmuch as the I.E.C. did not commit itself as to the fourth fundamental unit needed to obtain a comprehensive unit system, the writer should like to repeat the suggestion advanced in the foregoing reference, namely, to take charge as the fourth fundamental quantity. The coulomb should be chosen as the unit. Since all definitions of electrical quantities are based upon observable effects, either of mechanical or chemical nature, it seems irrevelant which one of the 7 units would be chosen as fourth fundamental unit. In favor of the charge it could be said that it is the only quantity having a natural unit in the electron or similar fundamental elementary charges. Readily available standards would be possible only for resistance; however, the difficulty in maintaining such standards over a long period of time is well known. Any theoretical definition of the ampere would be based upon the force action of 2 currents, just as the definition of the coulomb is based upon the force action of 2 charges. To use resistance as a convenient secondary standard is permissible in any case; the reduction of resistance to a secondary standard, moreover, has the added advantage that it would not be necessary to try to produce a standard of absolute accuracy, for all of these secondary standards could be compared at any time by absolute measurements with the fundamental unit of charge.

The choice of charge as the fundamental unit has been promoted also by D. Germani (*Rev. Gen. de l'Elec.*, v. 32, July 9, 1932, p. 39–50) and by G. A. Campbell (Nat. Research Council Bul. No. 93, 1933, p. 48–73).

A. E. Kennelly: The interesting and valuable discussion seems to have called for emphasis on the following points:

1. The I.E.C., in adopting the mks system, has made clear that the classical electric and magnetic cgs systems of Maxwell are in no way disturbed or interfered with. These systems have done so much valuable service to science over so many years, and scientific literature is so permeated by them, that their use must be expected to continue for a long time to come. If the Giorgi system meets with sustained approval, so that textbooks and papers are written in it to an increasing extent, it might be possible for the mks system ultimately to supersede the cgs system in all branches of science, but if so, the process is likely to be so gradual that the date of its completion is the vanishing point in the picture of our present scientific perspective. It is not incumbent upon us to speculate over an outcome so remote.

2. It would, of course, be desirable to have the question settled as to whether the Giorgi system should be rationalized or nonrationalized in the fields of electricity and magnetism. That is a matter on which international agreement will have to be attained in order to reach a settlement. How could a single nation, or any small group of nations, hope to effect a settlement of such a question, by themselves? The question in one form or another has been before the world for some 50 years, since it was first presented by Heaviside. It has already twice come up for a vote in the E.M.M.U. Committee of the I.E.C. On each occasion there was a majority, but only a small majority, in favor of rationalization, and it was decided to defer the matter until such time as there might be a closer approach to unanimity. In the S.U.N. Committee there has been evinced a distinct majority for nonrationalization, but it has been by no means an overwhelming majority. The final agreement, if and when attained, should secure a marked preponderance of votes both among physicists and engineers, if open dissension is to be avoided. Both sides of the question must be studied and tried out, therefore, before seeking international decision.

3. In applied magnetics, it is the relative permeability μ/μ_0 of a magnetic medium that is of principle concern to the engineer. This is, by general consent, a simple numeric, and is the same whether the mks or the cgs system is used. Similarly, in applied electrics it is the relative permittivity ϵ/ϵ_0 that is of engineering importance. Similarly, this is generally agreed to be a numeric, and is the same in both mks and cgs systems. It is often called the "dielectric constant." These valuable numerical constants are independent of the system and of rationalization alike.

4. The I.E.C. still has before it the unsettled question of a fourth fundamental unit for the Giorgi system, even though it is not necessary to wait for the decision in order to study and use the system. Valuable opinions on the question of choice have now been rendered by the 2 scientific organizations to which the I.E.C. referred the question. The first of these opinions, that of the Consultative Committee on Electricity (Comité Consultatif d'Electricité) of the International Commission on Weights and Measures, appears in English translation as appendix I of the paper. The other, by the S.U.N. Committee (of the International Union of Pure and Applied Physics), under the chairmanship of the late Sir Richard Glazebrook, is here presented in 2 documents: the formal reply of the S.U.N. Committee to the I.E.C. question and a less formal expression of opinion by Sir Richard Glazebrook, in a covering letter addressed to General Secretary Mr. C. le Maistre, of the I.E.C. It is probable that these 2 documents were the last scientific acts of Sir Richard Glazebrook's devoted service to science lasting over so many years. As known by all, he was the secretary of the B.A. Committee on Electrical Units, and was also director of the National Physical Laboratory, at Teddington. It was he who in 1904, at the International Electrical Congress of St. Louis, presented the resolutions that were then adopted and came to most useful fruition, namely: *a.* the establishment of the I.E.C., and *b.* the establishment of an International Commission, representing the various national physical laboratories for the maintenance of electric and magnetic units and standards. The functions of this

latter commission have been since formally taken over and adopted by the International Convention of Weights and Measures, at Sèvres. The world of physics and of engineering thus owes a great debt of gratitude to the work and devotion of Sir Richard Glazebrook.

The I.E.C. still has to consider the important question of the choice of a fourth fundamental unit for the Giorgi system. Whatever that decision may be, it is to be hoped that the standards embodying that unit, as well as all the other practical electromagnetic units, may be those maintained at Sèvres for the use of physicists and engineers alike.

Reply of S.U.N. Commission to I.E.C. Question

The following is essentially the full text of the formal reply of the S.U.N. Commission of the International Union of Pure and Applied Sciences to a request by the I.E.C. for recommendations concerning the adoption of a fourth unit in the mks system.

The S.U.N. Commission has given very careful consideration to the request of the I.E.C. for help in the selection of the fourth quantity which, in the view of the I.E.C., is required to complete the mks system of units, and desires to thank the I.E.C. for referring the question to the commission.

Table I which accompanies this reply has been prepared to show the relation between some of the quantities concerned in the mks and cgs systems, respectively.

The commission has consulted a large number of leading physicists and, with hardly any exception, the following resolution, proposed by Dr. Abraham, Secretary of the International Union of Pure and Applied Physics, has been approved.

"Considérant que lors de leur création les unités électromagnétiques du système pratique avaient été définis comme étant des multiples décimaux exacts des unités électromagnétiques cgs."

"Considérant que ces définitions initiales comportent plus de précision expérimentales et plus de securité que des définitions basées soit sur la conservation de certains étalons soit sur des techniques spéciales (colonnes de mercure, électrolyse)."

"La Commission émet l'avis:

Il n'y a pas lieu de modifier les définitions initiales des unités électriques du système pratique, définitions qui fixent pour ces unités des valeurs égales à des multiples décimaux exacts des unités du système C.G.S. électromagnétique."

The commission is pleased to learn from a letter (*Nature*, v. 136, July 20, 1935, p. 110) from Professor Marchant that at the I.E.C. meeting, although there is nothing in the minutes stating that the basis of the decision should be that the permeability of free space should be taken as unity, the reason why the question of the fourth unit was referred to the 2 Committees concerned was that the commission was anxious that whatever was chosen should be consistent with the cgs system of units. Table I gives effect to this view.

The S.U.N. Commission therefore recommends:

That the table appended to this report be accepted generally as defining the relation between the cgs and the mks systems of units.

The accepted system of electrical measurements is based on the reports of the British Association Committees on Standards for Electrical Measurements, 1861–1870, 1880–1912. The committee in 1863 decided to employ the "absolute" system of measurement which they explained in the following terms.

"The word 'absolute' in the present sense is used as opposed to the word 'relative' and by no means implies that the measurement is accurately made or that the unit implied is of perfect construction; in other words, it does not mean that the measurements or units are absolutely correct but only that the measurement instead of being a simple comparison with an arbitrary standard of the same kind as that measured is made by reference to certain fundamental units of another kind treated as postulates."

The fundamental units selected were those of length, mass, and time. For the construction of standards of measurement the knowledge is required of the forces between electrical and magnetic quantities expressed in these fundamental units. Theory shows that, under the conditions assumed by Maxwell, one additional quantity is necessary, and is sufficient, to give us that knowledge. Theory also shows that this quantity, usually denoted by the symbol μ_0 is a measure of the "permeability," the ratio, that is, of magnetic induction to magnetizing force, in "free space" the medium in which the measurements are supposed to be made. On the cgs system the value of μ_0 is assumed to be unity.

The mks system can be made absolute by the assumption of any convenient value for μ_0 but, if the units of that system are to be the practical units of the C.G.S. system, the value (on the rationalized system of units the value will be $4\pi \times 10^{-7}$) of μ_0 must be 10^{-7}.

In reply therefore to the request from the I.E.C. the S.U.N. Commission recommends:

That the fourth unit on the mks system be 10^{-7} henry per meter, the value assigned on that system to the permeability of space.

Table I—The Relation Between Quantities of the CGS Electromagnetic System and the Proposed MKS System

System	Length	Mass	Time	Magnetic Coefficient μ_0	Electromagnetic Coefficient A	Space Permeability μ_0/A	Coulomb	Ampere	Volt	Ohm
CGS	1 centimeter	1 gram	1 second	1	1	1	10^{-1}	10^{-1}	10^8	10^9
MKS	1 meter	1 kilogram	1 second	10^{-7}	1	10^{-7}	1	1	1	1

In a modern "Maxwell" theory of electricity the permeability of space, which is measured by the ratio μ_0/A, is assumed to be a quantity having dimensions. Its value, therefore, will depend on the system of units employed. In the cgs system the permeability of space has been selected as the unit of permeability. Hence on this sytem, since $A = 1$, the value of μ_0 is unity. In the mks system the value of μ_0 is 10^{-7} and in the "rationalized" mks system it is $4\pi \times 10^{-7}$.

At the same time the S.U.N. Commission desires to take this opportunity of placing on record their recognition of the fact that there are important electrical theories supported by a number of physicists in accordance with which $A = c$ the velocity of wave propagation and $\mu_0 k_0$ is a pure number.

Glazebrook's Opinion on the Fourth Unit of the MKS System

Sir Richard T. Glazebrook expressed his personal opinion regarding the fourth unit of the mks system by means of the following letter addressed to C. le Maistre, general secretary of the I.E.C.:

Ballards Oak,
Limpsfield,
Surrey.
30 November, 1935

Dear le Maistre:

It may, I trust, be helpful to add some remarks from myself in additon to the formal note which embodies the reply of the S.U.N. Commission to the question asked in the letter of June 27th from Dr. Kennelly.

The object of the I.E.C., like that of the B.A. Committee in 1863, is to provide a consistent system of definitions and measurement of electric quantities, and it is clear that for many purposes the mks has advantages over the cgs system. For electric measurements the mks system rests on the meter, the kilogram, and the second as fundamental units, with one quantity, μ_0, connecting electrical quantities with these units. That is all that is necessary, and it is this aspect of the matter which is dealt with in the reply from the S.U.N. Commission.

But the question may be viewed from another aspect; that of the mathematical theory of electricity. In the development of this theory we have to deal with a large number of electrical quantities which are connected together by laws expressed in the form of equations. Each term in such an equation is ordinarily the product of 2 quantities. One of these represents the unit in terms of which the quantity is measured, and the other a pure number indicating the number of times the unit enters into the equation. Thus if Ω represents the unit (1 ohm) a resistance of 10 ohms is properly represented by the symbol 10Ω.

Furthermore the unit may appear in the equation, raised to some power. Thus the area of a square whose side contains l units of length, each of unit length L, is $l^2 L^2$ square units of length, while if C represents the unit of current, the watts required to maintain a current containing c such units in a given circuit is proportional to c^2C^2. L and C enter these equations each raised to the power 2. We may have expressions in which some unit occurs raised to the power n. In this case n is said to measure the "dimensions" of the unit in the equation and an equation connecting the units of measurement of the quantities concerned without reference to the numbers by which

our units are multiplied is known as a dimensional equation.

Thus force is measured by the momentum produced per unit of time, and momentum by the product of the mass moved multiplied by the distance traversed per unit of time. We therefore say that the dimensions of force are 1 in mass, 1 in length, and −2 in time, and write the dimensional equation as $F = ML/T^2$ where M, L, and T are the units of mass, length, and time we have selected to work with. We have thus formed a dimensional equation between force, mass, length, and time. You will excuse, I trust, this elementary explanation, but I desire to make my meaning quite clear.

Now electrical theory enables us to form dimensional equations between all the various electrical and other quantities which occur in the theory. Moreover, we find that if we select any 4 (we cannot select C, E, and R, current, electromotive force, and resistance as 3 of the 4, for $C = E/R$ so that the 3 quantities reduce to 2) of these quantities which are independent of each other, it follows from the theory that the units of all the other quantities can be expressed in terms of these 4 units.

To form dimensional equations between electrical quantities we need 4 independent "fundamental" units and these may be any 4 of the whole series of quantities considered including mass, space, and time, but these equations will tell us nothing about the values of all the various numerical factors by which the units are multiplied in the series of equations required for the development of electrical theory; and without this knowledge we cannot construct practical standards of measurement.

The knowledge needed is given us in an "absolute" system of measurement by taking as 3 of our fundamental quantities, the units of length, mass, and time, and combining these with an arbitrary value for μ_0, which we may, if it is desired, call a fourth fundamental unit. Thus, a valued German correspondent, while insisting on the necessity for distinguishing between the establishment of methods of standardization "messtechnik" and electrical theory, as given in a series of mathematical equations, states:

"The Giorgi system is fully determined by the following premises:

1. The standards are m, k_g, s, μ_0.

2. Of its units, 3 agree completely with the standards (m, k_g, s) a fourth unit is $\mu_0 = 10^{-7}$ (or $4\pi \cdot 10^{-7}$); all other units can be derived from these by the principle of coherence.

3. If for any special purpose it is desired, or is necessary, to select 4 fundamental units every one can make his choice according to his own preference."

I have dealt with the questions raised in this letter more fully in papers which are being printed, but felt it might be useful to state in a letter the principles involved, without more mathematics than is necessary for their comprehension.

To sum up, if the mks system is to be adopted as an absolute system whose units agree with the practical units of the cgs system, it is necessary to assume 10^{-7} (or $4\pi \cdot 10^{-7}$) as the permeability of space and no other fourth unit is required.

To establish such a system is clearly part of the task properly undertaken by the I.E.C.

To tie up the future development of electrical theory by the statement that one of the existing units employed by electricians is to be treated as fundamental is not in my opinion a task which should be undertaken by the commission and might quite possibly prove (with our present knowledge of electricity) to be a retrograde step.

I write this, not as chairman of the S.U.N. Commission, but as one of those who at St. Louis in 1904 helped to establish the I.E.C. and who for many years took an active share in its work. As such, I desire to put on record my conviction that the selection by the I.E.C. of a fourth fundamental unit from among the practical units already adopted is unnecessary and might, as suggested to me lately by a prominent engineer, block scientific progress. But while this is so, I desire also to state my opinion that an mks system, based on the 4 quantities m, k_g, s, $\mu_0 = 10^{-7}$ has distinct advantages for the electrotechnician.

I have purposely avoided the question of rationalization but the letter applies, *mutatis mutandis*, to it also.

Yours very sincerely,

R. T. Glazebrook

Past Chairman of the Electrical Committee of the British National Committee, I.E.C.

Earth Resistivity and Geological Structure

Discussion of a paper by R. H. Card published in the November 1935 issue, pages 1153–61, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

C. L. Gilkeson (Edison Electric Institute, New York, N. Y.): Probably the 2 most important contributions to the study of low frequency inductive situations made by R. H. Card's paper are:

1. The data given in the paper will aid materially in making preliminary estimates of induced voltage in low frequency inductive exposures. In certain situations these estimates will be sufficiently accurate to eliminate the exposure from further consideration.

2. In cases which cannot be so eliminated, field tests are necessary. The data given in the paper should prove useful in planning the type of test to be made and in giving some warning of the difficulties which may be encountered in making them.

It is brought out in the paper that for exposures located in those parts of the country where the geological structure is of more recent formation, for instance, most of the Mississippi valley, estimates of earth resistivity may be made with considerable assurance that they will not depart widely from values that would be measured in such locations. On the contrary, when the exposure is located in a part of the country where the geology indicates that the rocks are of the oldest geological age, and especially where rocks of several different geological periods are present, estimates of earth resitivity cannot be made with any degree of accuracy. For such situations preliminary estimates should be based on the highest value of earth resistivity to be expected in such an area. In any case, if the preliminary estimates of induced voltage indicate that a low frequency inductive co-ordination problem may exist, measurement of the actual coupling or earth resistivity clearly is indicated as the next step in the study. In areas where the geological structure indicates high resistivity, tests preferably should cover the entire route of the exposure since experience has indicated that wide variations of earth resistivity may be encountered within the limits of an exposure for such areas.

An extreme case of such a situation was encountered in coupling tests made about a year ago in the southern part of South Carolina. Geological maps for this area indicated pre-Cambrian rocks and post-Cambrian intrusive rocks of igneous origin. The tests were made using a primary circuit about 50 miles in length, energized with ground return current at a frequency of 60 cycles per second. Voltages were measured in ground return circuits of 500 to 3,000 feet in length, laid parallel to, and near the center of, the energized circuit at separations up to 10,000 feet. Based upon many measurements made in an area of about 2 square miles (2 miles along the length of line and one mile perpendicular) an average effective earth resistivity of about 14,000 meter ohms was indicated.

Tests were first made on a single array of exploring wires laid parallel to the line at various separations from it. These tests indicated that a variation in earth resistivity of 3 to 1 between adjacent exploring wires was not uncommon. Tests made in a number of 500 foot exploring wires at the same separation indicate that for consecutive 500 foot sections along the line variations of earth resistivity of 2 to 1 were not uncommon.

Large irregularities in earth resistivity have been encountered in tests made in other places where the geological structure indicated rocks of high resistivity and of different geological ages. Errors in calculated coupling based upon measurements on one set of exploring wires may be large when the exposure is located in such an area. It is therefore highly desirable to appreciate this difficulty at the time tests are planned, and wherever practical to determine the coupling over the entire route of the proposed line.

Although the foregoing discussion refers only to the magnitude of induced voltage, it is but one of a number of factors of a consideration of the importance of an inductive exposure. Other factors of equal or greater importance are the probable frequency of occurrence of induced voltages of various percentages of the estimated maximum, the distribution of the induced voltages in the telephone plant, and the effect of these voltages. From the viewpoint of the communication company the effect of induced voltages depends among other things upon their duration and the type of telephone line.

G. Wascheck (Bell Telephone Laboratories, Inc., New York, N. Y.): R. H. Card's attempt to correlate the results of a-c coupling tests and d-c resistivity measurements to the geological structure of the earth in particular vicinities represents a notable advancement toward an

orderly classification of such data obtained over the entire country. Moreover, this work is believed to be of use in the estimation of resistivities in cases where tests have not been made and where such information is required for inductive co-ordination problems.

It is gratifying to see that recognition has been given to the effect of the earth at considerable depth upon the effective resistivity to be employed in computing the coupling of earth return circuits at power frequencies. Too little attention has been given to this, especially in d-c exploration tests where resistivities near the surface as well as several hundred, or even several thousand feet, below the surface must be investigated before an effective value for alternating current may be determined. To this point the figures in the appendix of the paper are pertinent, for they define the necessary limit of depth of exploration for several apparently uniform structures. In practice this rarely is so simple as stated. Usually 2 or more layers are indicated in the first hundred or more feet below the surface, and of such proportion that it becomes difficult to determine even the probable distribution of currents between them at a given frequency, much less the effect of an underlying layer. However, an equivalent 2 layer structure, which is a fair electrical approximation to the actual earth, usually may be postulated.

In Europe attention given to investigations of this nature is shown in the preparation of an electrical resistivity map of England, Wales, and South Scotland published by the British Electrical and Allied Industries Research Association, reference to which is made in an article by Smith-Rose in the proceedings of the Physical Society of London, for September 1935.

Parallel Inverter With Resistance Load

Discussion and author's closure of a paper by C. F. Wagner published in the November 1935 issue, pages 1227–35, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

C. C. Herskind (General Electric Co., Schenectady, N. Y.): The use of grid controlled mercury arc rectifiers has been proposed for inverters for applications involving frequency changing and d-c transmission. Many different types of inverter circuits have been proposed for these applications, and the engineer is faced with the problem of deciding the relative merits of the various types.

The writer wishes to point out that inverter operation involves one problem not met in a rectifier circuit. This is the problem of commutation. Therefore, in order to compare the various types of inverter circuits, it is essential to know their characteristics and limitations with respect to wave form and commutation.

This paper provides a sound basis for the application of the parallel inverter; however, in actual practice, a pure resistance load rarely is used, and the more usual load consists of an inductor and a resistor in series. The writer would like to ask the author whether he has made any studies of circuits involving combination loads consisting of inductance and resistance in series. Another case requiring consideration is that of a counter electromotive force load of sinusoidal wave form.

The method of analysis here disclosed should be extended to the analysis of other inverter circuits, in order that the engineer may utilize these circuits intelligently.

C. F. Wagner: In reply to C. C. Herskind's question regarding studies of circuits of a similar nature involving reactance as well as resistance in the load, the author refers him to a paper already submitted for publication by the A.I.E.E.* This paper considers the characteristics of single phase parallel inverter circuits with static loads consisting of resistance and inductance.

* **Editor's Note:** This paper has been approved for publication and is scheduled for inclusion in a future issue.

Current Harmonics in Nonlinear Resistance Circuits

Discussion and author's closure of a paper by Thurston D. Owens published in the October 1935 issue, pages 1055–57, and presented for oral discussion at the electrophysics session of the winter convention, New York, N. Y., January 28, 1936.

Theodore Brownlee (General Electric Co., Pittsfield, Mass.): T. D. Owens has used roundabout methods in attacking a simple problem. Instead of the laborious use of determinants to evaluate the coefficients in his Fourier series, a direct solution that is applicable to any number of ordinates can be obtained. Any text dealing with the subject shows that if one lobe of a symmetrical sine wave is divided into q equal parts starting at zero degrees

$$A_m = \frac{2}{q}\sum_0^q M_n \sin m_n\theta_1$$

where

A_m = maximum value of the sine term of the mth harmonic
M_n = value of the nth ordinate
$\theta_1 = \frac{180°}{q}$ = distance between ordinates

As Owens points out, only sine terms and odd harmonics are to be considered.

Ordinarily q is taken as an even number, and since the wave is symmetrical about the 90° or $(q/2)$th ordinate, it is found that all ordinates and their multipliers are paired except at 90°. Also the 0 and q ordinates are zero. Hence, for such a symmetrical wave, the preceding equation becomes:

$$A_m = \frac{4}{q}\sum_1^{(q/2)-1} M_n \sin m_n\,\theta_1 + \frac{2}{q}\,M_{q/2}\sin m\,90°$$

The multipliers K used by Owens greatly simplify the calculations for any given value of θ_1. They can be easily calculated using the above equation. For example, when $\theta_1 = 15°$,

$$A_1 = \frac{1}{3}\,[M_1 \sin 15° + M_2 \sin 30° + \ldots + M_5 \sin 75°] + \frac{1}{6}\,M_6 \sin 90°$$

whence 6 equations of the simple form

$$K_{1,n} = \frac{1}{3}\sin(n\cdot 15°)$$

It would seem that Owens' table I has its rows and columns interchanged.

The general application gives a method of determining the current harmonics in an arbitrary resistance network of which only the over-all volt-ampere characteristic is known. Such a roundabout procedure is not necessary, for the 15 degrees ordinates of the current wave can be obtained directly from the volt-ampere curve and the 15 degrees ordinates of the applied voltage. If the 15 degrees ordinates of the current wave are known, the amplitudes of the various harmonics can be obtained directly by use of Owens' table I (with rows and columns properly labeled).

It should be noted that unless the volt-ampere characteristic of the resistance network follows an exponential law (which gives a straight line on log-log co-ordinate paper), the relative amplitudes of the various harmonics depend upon the magnitude of the sinusoidal impressed voltage. For example, if a linear resistor is placed in series with a "thyrite" resistor and a sinusoidal voltage is applied, the current wave will contain pronounced harmonics at low voltages, but practically none at high voltages.

A. A. Nims (Newark College of Engineering, Newark, N. J.): T. D. Owens' paper is interesting for its ingenious reduction of the problem to an exercise in harmonic analysis. The approach to this problem is similar to the Runge-Grover method outlined in the Bulletin of the Bureau of Standards, v. 9. There the solution is in general terms for a finite number of points or ordinates, and the simultaneous equations are simplified by the process of multiplication and addition, instead of being solved by determinants. It is suggested that forms of the type there outlined would be as convenient and as economical of time as the procedure outlined by Owens. The writer has used them for a number of years and is developing them further.

T. D. Owens: The discussions by Theodore Brownlee and A. A. Nims are distinct contributions to the subject covered in the paper.

Brownlee points out that the K coefficients can be calculated with a minimum amount of labor by using certain standard formulas he gives. These formulas actually were used in checking the table of coefficients given in the paper, and their use is strongly recommended.

Through a typographical error the columns and rows of the table of coefficients are reversed. If the subscripts of K_{1n}, $K_{2n} \ldots K_{6n}$ be made to read K_{n1}, $K_{n2} \ldots K_{n6}$, the table will be correct as it stands.

News
Of Institute and Related Activities

Student Conference Held by South West District

What has been said to be the most successful Student conference ever held by the Institute's South West District (number 7) was held May 1–2, 1936, at the University of Arkansas, Fayetteville. The program included 2 Student technical sessions, a dinner meeting, and the annual business meeting. The attendance consisted of 110 Students and 26 counselors, faculty members, and national officers, making a total of 136.

The following papers were presented at the 2 Student technical sessions:

A Graphical Analysis of the Harmonics in a Class A Amplifier, T. J. McMullin, Agricultural and Mechanical College of Texas, College Station.

A Mercury Vapor Stroboscope, K. E. Dueker and C. H. Sutter, University of Kansas, Lawrence.

The Application of Photoelectric Cells to Colorimetric Determinations in Micro-Chemical Analyses, W. L. Pursell, Oklahoma Agricultural and Mechanical College, Stillwater.

Current Control in D-C Arc Welding Machines, Frank M. Neil, Southern Methodist University, Dallas, Texas.

A Study in Rural Electrification, Philip R. Watson, University of Missouri, Columbia.

Electrolytic Corrosion of Pipe Lines, Vincent Lee Nealy, Rice Institute, Houston, Texas.

Characteristics of Improved Repulsion Induction Motor, R. L. Fisher and K. O. Hanson, Missouri School of Mines and Metallurgy, Rolla.

Starting Characteristics of Three-Phase Squirrel-Cage Induction Motors, P. R. Harris and C. E. Joseph, University of Arkansas, Fayetteville.

An Optical Selsyn Device for an Electrical Telegraph, Elmer H. Schultz, University of Texas, Austin.

Characteristics of Mismatched T Type Filters, Howard T. Pyle, University of Missouri, Columbia.

An Electronic Tube Wattmeter, Jerry Zazvorka, University of Texas, Austin.

Generators for Wind-Electric Plants, J. W. York, Kansas State College, Manhattan.

Calculating Board as Applied to Small Power Systems, Mark Townsend, Texas Technological College, Lubbock.

Prizes for Student papers were awarded as follows: First award in the graduate contest was given to Howard T. Pyle, and first award in the undergraduate contest was given to Philip R. Watson, both of the University of Missouri, Columbia. Each prize consisted of a certificate of award and choice of either Student or Associate A.I.E.E. badge. In addition, each winner was given a plaque for the permanent possession of his Student Branch.

At the dinner meeting held on the evening of Friday, May 1, the following addresses were presented:

Early History of Alternating-Current System, Donald E. Garr, Kansas State College, Manhattan.

The Next Fifty Years in Electrical Engineering, F. J. Meyer (A'13, M'17), vice-president, South West District, A.I.E.E., Oklahoma City, Okla.

The annual business meeting of the conference was held Saturday morning, May 2, with Counselor Chairman R. G. Kloeffler of Kansas State College, Manhattan, in the chair. Reports were made by the several Branch chairmen; some of the features of Branch organization and activities brought out in these reports are:

1. The formation in the Branch of technical committees similar to those of the national society. Each technical committee attempted to supply one or more programs and speakers for Branch meetings.

2. The securing of some outside speakers of interest to all engineering students.

3. Several short extemporaneous talks (of one minute duration) by Student members of the Branch at each meeting.

4. Conduct of a course in the use of slide rule for freshmen and sophomores.

An invitation from the A.I.E.E. Dallas Section to the counselors to hold the next annual Student conference in connection with the District meeting in Dallas, Texas, in October 1936, was accepted, unanimously.

Prof. J. S. Waters of Rice Institute, Houston, Texas, was elected counselor-chairman for the ensuring year. Conference committee chairmen were: R. C. Eldredge, registration; W. H. Mapes, program; and L. C. Barry, dinner.

South West District Meeting at Dallas

Dallas, Texas, will be host to the 3 day meeting of the A.I.E.E. South West District, October 26–28, 1936. At that time the $25,000,000 Texas Centennial Exposition, with its more than 50 buildings housing exhibits that depict art, science, commerce, industry, education, and culture, will be in full swing.

The meetings and papers committee, under the chairmanship of Lee Cook, has been busily engaged for some time arranging for a technical program of wide interest that will have special appeal for engineers in the Southwest. Other details will be announced in subsequent issues.

The personnel of the District meeting committee making the arrangements is as follows: L. T. Blaisdell, *chairman;* F. J. Meyer, vice president, A.I.E.E. South West District; B. D. Hull; E. W. Burbank, hotels and registration; Lee Cook, meetings and papers; A. B. Emrick, entertainment and reception; E. T. Gunther, finance; H. G. Mathewson, transportation and inspection; John Oram, attendance and publicity; J. S. Waters, chairman, committee on Student activities, 1936–37.

Summer Convention at Pasadena Well Attended

As this issue goes to press, the A.I.E.E. 1936 summer convention at Pasadena, Calif., is being held. Attendance at initial sessions is reported to have been unusually large. The first day's registration was 570, and on the second day it was estimated that an additional hundred registered, with more expected on the remaining days of the convention.

At the annual business meeting of the Institute held on the first day of the convention, the report of the committee of tellers was presented and the following officers were declared elected, each to take office August 1, 1936:

President:

A. M. MacCutcheon, engineering vice president, Reliance Electric and Engineering Company, Cleveland, Ohio.

Vice Presidents:

A. C. Stevens, in charge of educational sales, General Electric Company, Schenectady, N. Y.
O. B. Blackwell, manager of staff departments, Bell Telephone Laboratories, Inc., New York, N. Y.
C. Francis Harding, head, school of engineering, and director of the electrical engineering laboratories, Purdue University, West Lafayette, Ind.
L. T. Blaisdell, southwestern district manager, General Electric Company, Dallas, Texas.
C. E. Rogers, chief engineer, Pacific Telephone and Telegraph Company, Washington-Idaho area, Seattle, Wash.

Directors:

K. B. Meachron, research engineer in charge of high voltage practice, General Electric Company, Pittsfield, Mass.
C. A. Powell, manager, central station engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
R. W. Sorensen, professor of electrical engineering, California Institute of Technology, Pasadena, Calif.

National Treasurer:

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The board of directors for the administrative year beginning August 1, 1936, consists of these newly elected officers, together with the following hold-over officers: E. B. Meyer (retiring president), Newark, N. J.; J. B. Whitehead, Baltimore, Md.; C. V. Christie, Montreal, Que.; R. H. Fair, Omaha, Neb.; Mark Eldredge, Memphis, Tenn.; W. H. Harrison, Philadelphia, Pa.; N. B. Hinson, Los Angeles, Calif.; F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; L. W. W. Morrow, New York, N. Y.; and G. C. Shaad, Lawrence, Kans.

A full report of the various features of the summer convention is scheduled for publication in the August issue.

Additional Awards for 1935 Institute Papers

In addition to the national and District prize awards for papers presented before the Institute during 1935 announced in ELECTRICAL ENGINEERING for June 1936, pages 754–5, the awards for Districts 8 and 9 have now been announced. These awards are:

DISTRICT 8

Prize for best paper awarded to Abe Tilles (A'30) for his paper "Spark Lag of the Sphere Gap," presented at the Pacific Coast convention, Seattle, Wash., August 27–30, 1935.

Prize for initial paper awarded to T. A. Rogers (A'31) for his paper "Test Values of Armature Leakage Reactance," presented at the Pacific Coast convention, Seattle, Wash., August 27–30, 1935.

Prize for Branch paper awarded to F. N. Merralls for his paper "Recent Recording Technique for Immediate Playback," presented at a joint meeting of California Institute of Technology Branch and Los Angeles Section, April 16, 1935.

DISTRICT 9

Prize for initial paper awarded to T. J. Killian (A'35) for his paper "Gaseous Discharge Lamps Having External Electrodes," presented at a meeting of the Seattle Section, February 19, 1935.

Prize for Branch paper awarded to R. J. Biele and D. W. Pugsley for their paper "Some Polarity Characteristics of Sphere Gap Sparkover," presented at a meeting of the University of Utah Branch, May 14, 1935.

Junior Engineers of Providence Organize

In line with a suggestion made last fall by General R. I. Rees, chairman of the committee on professional training of the Engineers' Council for Professional Development (E.C.P.D.), the Junior Engineers' Group for Professional Development of the Providence (R. I.) Engineering Society was organized March 2, 1936. As plans mature and hopes are realized, it is expected that other centers of the engineering profession will try similar experiments.

Following General Rees's exposition of the junior movement, a committee of 12 prominent engineers and educators of the Providence Engineering Society, with Alton C. Chick as chairman, distributed a preliminary questionnaire to 600 engineers not more than 5 years out of college and other young men definitely following lines of engineering activity. To form a nucleus for the organization, a selected group of 20 junior engineers was appointed, who chose as officers Robert Anthony, Jr. (Yale), chairman, Roger P. Condon (M.I.T.), vice-chairman, and John R. Pearson (R. I. State), secretary-treasurer. In discussions relating to a program, this group agreed that personal contacts and self-expression were the 2 chief benefits to be derived from the proposed activities.

In the meantime 151 replies to the questionnaire have been received. These may be classified as follows: (1) Interested in paper by junior engineers, 129; (2) interested in group discussion, 145; and (3) interested in formal study, 136. Thirty-seven topics for group discussions were voted on, of which the most popular were: (*a*) Production control and time study, 39; (*b*) air conditioning, 26; (*c*) personnel relations, 26; (*d*) marketing, 14. The most popular of the 35 suggested topics for formal study were: (*a*) Business law, 54; (*b*) public speaking, 43; (*c*), cost accounting, 23; (*d*) differential equations, 14; and (*e*) power plant subjects, 8.

At the first general meeting, held April 20, and attended by 250 juniors, a program was proposed. At a subsequent meeting on May 4 several groups were set up, each with a junior engineer as a group leader. The management group is interested in manufacture and managerial technique. The power group is concerned with steam plants, Diesel power, and general plant engineering. A third group contains those who wish to discuss the general economic background of the Providence industrial area. The construction contingent will not carry on study through group discussion but will have a class in formal study. There is also a machine design group. Other groups will be organized as the need arises.

Beginning next fall, it is proposed to engage the services of a lawyer to give a series of lectures on business law, including contracts and specifications. Twenty-five men are contemplating courses leading to the degree of master of engineering, probably at Brown University.

To provide a constructive basis for discussion, members will make contributions on certain topics or projects. For example, the machine design group will start a study of springs and their uses; the power group hopes to assemble and tabulate useful information on combustion and air conditioning; while the economic group will consider such a project as "what business to embark on in Rhode Island if $100,000 were made available with which to do it." This latter project may be expanded to include other groups, because if a manufacturing enterprise is decided upon as the solution, construction engineers may study the building problem, power engineers the power equipment, machine designers the design and adaptation of machinery, and the management group personnel problems, plant operation, and estimates of cost.

An interesting experiment in co-operative post-collegiate study thus has been launched by the E.C.P.D., which is an agency for getting engineers and engineering organizations to develop themselves and the profession.

John Hays Hammond, Noted Engineer, Dies

On June 8, 1936, John Hays Hammond, noted mining engineer, died of a heart attack at his home in Gloucester, Mass., at the age of 81. He was born in San Francisco, Calif., March 31, 1855, and received his early education in public and private schools in that city. His professional training was received at Sheffield Scientific School, Yale University, and at the Royal School of Mines, Freiberg, Saxony, Germany.

His achievements are perhaps too well known to require detailed comment here. He examined properties in all parts of the world, and served as mining engineer in many different countries. He was one of 4 leaders in a reform movement in the Transvaal, in Africa, during 1895–96. In his autobiography, published on his eightieth birthday, he referred to that time as the most critical period of his life. After the Jameson Raid, with which he was not in sympathy, he was arrested and sentenced to death; the sentence afterward was commuted to 15 years imprisonment, and later he was released on payment of a fine of $125,000. Although he never was a candidate for public office and refused such appointive offices as cabinet positions, he exerted a powerful influence in politics and statecraft both in the United States and in the British Empire.

Annual Convention of Association of Iron and Steel Engineers. Approximately 35 technical papers, covering every phase of steel mill operations, will be presented by leading authorities at the 32d convention and iron and steel exposition of the Association of Iron and Steel Engineers. This yearly meeting will be held in Detroit, Mich., September 22–25. Among the features of the convention will be the inspection trips to the Ford Motor Company and the Great Lakes Steel Corporation. The latter has just put into operation its new 96 inch hot strip mill, while the Ford Motor Company recently completed and put into service a 54-inch hot strip mill.

Membership—

Mr. Institute Member:

Membership work continues all the year, so as you may make contacts this summer with those who you think worthy to be invited to join the Institute; send their names to the chairman of your Section membership committee, who is working all summer also.

Everett S. Lee

Chairman, National Membership Committee

Edison "Living Memorial" Endorsed by E.E.I.

Without a dissenting vote the Edison Electric Institute, at its recent annual meeting in St. Louis, Mo., gave its endorsement to the "living memorial" now being established by the Thomas Alva Edison Foundation. Like other great industries that owe so much to Edison, the electrical industry will benefit from the plan of the Foundation since it is expected that many of those who are trained under the plan will make contributions to electrical development. The Foundation plans each year to select 100 exceptional young people whose aptitudes especially fit them for further education in the careers they have chosen. These Edison scholars will be known as the "living memorial" to the great inventor. In addition, the Foundation is to perpetuate Edison's memory by preserving his library, laboratory, and shops at West Orange, N. J., where he spent so many active years developing his great inventions.

Owen D. Young, chairman of the board of directors of the General Electric Company and long identified with the electrical industry, is national chairman of the Thomas Alva Edison Foundation, and among its directors are the leaders of the electrical industry as well as many who are prominent in education and other industries. An announcement of the organization and officers of the Foundation appeared in the November 1935 issue of ELECTRICAL ENGINEERING, page 1274.

N.R.C. Committee on Insulation to Meet

The Ninth Annual Meeting of the committee on electrical insulation, division of engineering and industrial research, National Research Council, will be held at the Massachusetts Institute of Technology, Thursday, Friday, and Saturday, November 5, 6, and 7, 1936. Contributions to the technical program, reports on research in progress, and discussion in the field of dielectric theory and insulation should be sent to Dr. J. B. Whitehead (A'00, F'12, and past-president) chairman, The Johns Hopkins University, Baltimore, Maryland.

Bradley Stoughton Becomes Dean of Engineering

By recent action of the board of Trustees of Lehigh University, Bethlehem, Pa., Prof. Bradley Stoughton, head of the department of metallurgy, has become Lehigh's first dean of engineering. The growth of engineering at Lehigh has continued steadily for many years, until finally co-ordination of the various engineering departments under one head became advisable.

As secretary of the American Institute of Mining and Metallurgical Engineers from 1913 to 1921 Professor Stoughton made a host of friendships throughout the engineering world. During the stress of the war years he served on numerous national committees. In 1922, under the administration and support of President Harding, he prepared a report on the 12 hour day in the steel industry, resulting in the adoption of the 8 hour day.

In 1923, he was called to Lehigh to occupy the chair in metallurgy left vacant by the death of Joseph W. Richards. Previous to his secretaryship, he had been adjunct professor of metallurgy at Columbia University with Prof. Henry M. Howe, and while there, in 1908, had written his "Metallurgy of Iron and Steel," for 25 years the standard text in this field in the English language. In 1922, he was elected president of the American Electrochemical Society.

Dean Kimball of Cornell Retires

The retirement, this year, of Dexter S. Kimball, dean of engineering at Cornell University, Ithaca, N. Y., recently was announced. He was born in New Brunswick, Canada, October 21, 1865, and graduated from Stanford University in 1896. He went to Cornell in 1899, remaining until 1901 when he became works manager for the Stanley Electric Manufacturing Company. He returned to Cornell in 1904, and in 1920 he became the first dean of the combined colleges of engineering.

Dean Kimball is a past-president of The American Society of Mechanical Engineers (1921–22), of the Society for the Promotion of Engineering Education (1922–23), and of American Engineering Council (1926–28), and has received many honors. He is the author of 6 well-known books, and has contributed many articles and papers to scientific and engineering periodicals.

A.S.T.M. Committee on Insulating Materials Meets

At a 2 day session on March 19 and 20 in New York, N. Y., committee *D*-9 on electrical insulating materials of the American Society for Testing Materials reported much progress in advancing its work. In addition to completing work with regard to revisions of standard and tentative specifications and tests, there was outstanding discussion at the main committee and subcommittee meetings centering around such items as test cells for power factor and resistivity measurement of insulating oils, dielectric strength test of sheet and tape material, and conditioning requirements. In connection with insulating oils, committee *D*-9 has been attempting to secure a suitable test cell that would be inexpensive, but at the same time accurate and convenient to use. Several types of cells have been compared, and the laboratory results prompted considerable discussion. This involved the extremes in accuracy that might be desired by different interests, such as cable oil manufacturers, cable manufacturers, and operating companies. It is reported that these discussions and tests are bringing to light the desired information concerning the exactness of the present knowledge and limitations of equipment and measuring devices for power factor and resistivity of liquid insulation.

The committee is proposing a complete revision of the A.S.T.M. publication "Tentative Methods of Testing Electrical Insulating Materials for Power Factor and Dielectric Constant" (*D* 150–35 *T*). In this revision, the limits of accuracy of the different methods recommended are discussed. In order to summarize and interpolate the large amount of data on life tests collected by subcommittee IV on insulating mineral oils, the chairman, E. A. Snyder, Socony-Vacuum Oil Company, and F. M. Clark (A'24) physicist, General Electric Company, have prepared a paper for presentation at the A.S.T.M. annual meeting in Atlantic City. This will give an up-to-date picture of the present knowledge of oxidation and sludging of oils. This subcommittee announced that it is now ready to undertake "round-robin" tests to determine gas content of insulating oil.

A round-robin series of tests is to be undertaken in connection with the development of standard molds for use in testing molded materials. Another round-robin test is in progress dealing with power factor measurements of natural mica. This work is one of considerable technical difficulty and the committee now feels that it has developed a method due to the application of pressure on the electrodes which appears very promising. Under the sponsorship of subcommittee III on plates, tubes, and rods, a test series to study heat distortion of insulating plates is to be started and this subcommittee plans other tests in connection with identifying grades.

One activity of subcommittee VIII on papers and fabrics has to deal with the dielectric strength of tape material. The A.S.T.M. requirements have been criticized and study of the situation has resulted in definite work on the part of committee *D*-9 to attempt to provide a method that will be satisfactory to all concerned.

The special subcommittee on conditioning has been attempting to standardize the methods within the committee as far as

Future AIEE Meetings

South West District Meeting
Dallas, Texas, Oct. 26–28, 1936

Southern District Meeting
Birmingham, Ala., Dec. 1936

Winter Convention
New York, N. Y., Jan. 25–29, 1937

North Eastern District Meeting
Buffalo, N. Y., May 1937

Summer Convention
Milwaukee, Wis., June 21–25, 1937

Pacific Coast Convention
Spokane, Wash., Date to be determined

Middle Eastern District Meeting
Akron, Ohio, Fall 1937

Newly Elected A.I.E.E. National Officers

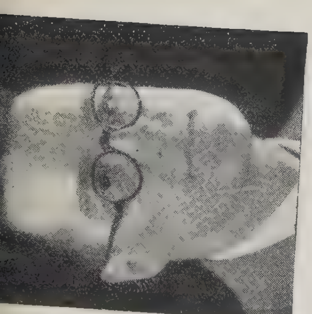
C. FRANCIS HARDING
Vice President
Head, School of Engineering, and Director of the Electrical Engineering Laboratories, Purdue University, West Lafayette, Ind.

L. T. BLAISDELL
Vice President
Southwestern District Manager, General Electric Company, Dallas, Texas

R. W. SORENSEN
Director
Professor of Electrical Engineering, California Institute of Technology, Pasadena, Calif.

A. M. MacCUTCHEON
President
Engineering Vice President, Reliance Electric and Engineering Company, Cleveland, Ohio

O. B. BLACKWELL
Vice President
Manager of Staff Departments, Bell Telephone Laboratories, Inc., New York, N. Y.



K. B. McEACHRON
Director
Research Engineer in Charge of High Voltage Practice, General Electric Company, Pittsfield, Mass.

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R. W. SORENSEN
Director
Professor of Electrical Engineering California Institute of Technology, Pasadena, Calif

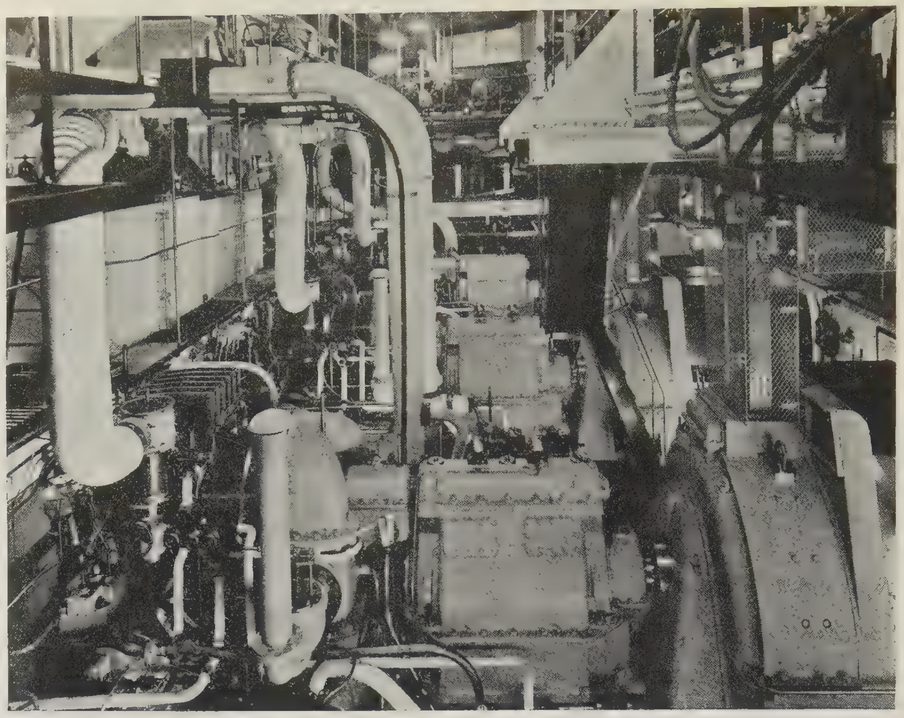
K. B. McEACHRON
Director
Research Engineer in Charge of High Voltage Practice, General Electric Company, Pittsfield, Mass.

C. A. POWEL
Director
Manager, Central Station Engineering Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

possible. At the present time, it is undertaking a study of ovens with a view to developing a standard oven. In this work it will contact the manufacturers so that the final product will be satisfactory from a test standpoint and will be economical to produce.

T. Smith Taylor (M'21) professor of physics, Washington & Jefferson College, Washington, Pa., is chairman of A.S.T.M. committee *D*-9, and E. J. Rutan (A'20, M'29) superintendent, test bureau, The New York (N. Y.) Edison Company, Inc., is secretary.

After Turbogenerator Room in the Liner "Queen Mary"



ELECTRICITY is used extensively in the operation of the new Cunard White Star liner "Queen Mary" and in providing for the comfort and convenience of the passengers. All deck machinery, such as steering gear, windlass, capstans, winches, etc., is operated electrically; in the boiler rooms all auxiliary machinery, with one or two exceptions, is operated by electricity. There are 2 independent but interconnected power stations on the liner. The forward power station supplies current for the hotel services and deck machinery and contains 3 1,300 kw units. The after power station, shown in the accompanying illustration, contains 4 units of similar capacity and furnishes power for the pumps and boiler room auxiliaries. Each generator is driven at a speed of 600 rpm through gearing by a separate steam turbine running at 5,000 rpm. Each turbine is provided with a separate condenser, with independent vacuum-maintaining pumps, ejectors, and lubrication systems.

Schenectady's Half Century of Electrical Progress

To commemorate the 50th anniversary of the establishment of the electrical industry in Schenectady, N. Y., by Thomas Alva Edison, a celebration was held in that city June 12–13, 1936, under sponsorship of the local chamber of commerce. It was just 50 years ago on June 14, which this year was on Sunday, that Edison took title to 2 abandoned shops of the McQueen Locomotive Company as a new location for the Edison Machine Works, thus laying the foundation for a local industry which later developed into the present General Electric Company.

To business and industrial leaders from all sections of the country attending the festivities, the outstanding event of the 2 day celebration was a formal dinner on Friday evening for more than 500 invited guests at which the chief speakers were Owen D. Young, chairman of the board of directors of the General Electric Company, Dr. George R. Lunn, New York State public service commissioner, Charles A. Edison, son of the famous inventor, and W. S. Barstow (A'94, F'12, and life member), Edison pioneer and president of the Thomas Alva Edison Foundation. Dr. Dixon Ryan Fox, president of Union College, Schenectady, acted as toastmaster.

Other events of the opening day's celebration included a ceremony changing the name of Schenectady's River Road to Rice Road in honor of E. W. Rice, Jr. (A'87, M'88, F'13, HM'33, and past-president; deceased November 25, 1935), pioneer electrical engineer and second president of the General Electric Company; cutting of a 25 foot birthday cake; and turning on 2 new sodium vapor lighting systems at either end of the city's main thoroughfare.

Events on the second day's program included a flag-raising ceremony at the General Electric Schenectady works, followed by an open house at the works with members of the General Electric Quarter Century Club acting as guides for the more than 5,000 visitors who inspected the plant. In addition, there were various sports and entertainment features which drew a crowd estimated at 50,000 people from a radius of 75 miles. The community activity as a whole was said to transcend any previous celebration in Schenectady's history.

At the formal dinner, Mr. Young called attention to the lesson that the life and work of Edison holds not only for an individual, but also for an organization or a nation. Remarking on the swift strides of electrical progress, he stated: "So rapidly came invention and improvement, fostered by research, that in this growing art it could never be said today that what is—is. It could only truthfully be said that what is—is not, in the sense that what is, is too obsolete. The whole history of the 50 years shows that what is not—can be, and will be."

"Mr. Chairman," he concluded, "we celebrate tonight more than what has been. We celebrate the unreality of what is and the certainty of what is to be. By so doing, we assert that a nation, like a man, recovers from depression by confident effort and not by hopeless surrender. If that be the lesson of this occasion, you will have rendered the greatest service to your countrymen."

In his talk, Dr. Lunn traced the development of the electrical industry and its relationship to present-day improved standards of living, and then drew upon a conversation he once had with Steinmetz and Marconi to point a prophecy that electrical progress is still, as Marconi put it, "in the kindergarten class."

"We recognize as great," he remarked in conclusion, "those men who can make 2 blades of grass grow where one grew before; what shall we say of the electrical industry which has made thousands of blades of grass grow where but one grew before? In all this work we recognize real creators of wealth—wealth which cannot be estimated in terms of money but in terms of greater ease, comfort, and happiness; this real wealth which may be enjoyed throughout all nations of the world who, I am sure, would join me in heartily congratulating you on this 50 years of progress."

Mr. Edison, after thanking the chamber of commerce for the tribute to his father, also prophesied continued progress for the industry. "The present is sometimes referred to as the electrical age," he said, "but Mr. Edison once remarked 'Not until every task now done by human effort is being accomplished by the application of electrical energy shall we have a true electrical age.' "

Mr. Barstow outlined the history of the Edison Pioneers and the events leading to the formation last year of the Thomas Alva Edison Foundation. He explained its purposes and its plans not only to commemorate the great inventor by erecting a permanent memorial tower at Menlo Park and by preserving his laboratory and library at West Orange, but also by creating scholarships to give financial aid to youths who show encouragement for scientific development but who are barred from the present type of scholarships.

New E.E.I. Officers. At the recent meeting of the Edison Electric Institute held in St. Louis, Mo., election of the following new officers was announced: president, C. W. Kellogg (A'19, M'23) chairman of the board of directors of Engineers Public Service Company, New York, N. Y.; treasurer, F. H. Nickerson, Consolidated Edison Company, New York, N. Y.; trustees, C. W. Kellogg, A. C. Marshall (A'14, F'29) vice president and general manager, Detroit (Mich.) Edison Company, and Edward Reynolds, Jr., president, Columbia Gas and Electric Corporation, New York, N. Y.

A.S.T.M. Elects Officers. At the first session of the annual meeting of the American Society for Testing Materials, Atlantic City, N. J., June 30, 1936, election of the following officers for the year 1936–37 was announced: President, A. C. Fielder, chief engineer, Experiment Stations Division, U.S. Bureau of Mines, Washington, D. C.; vice president, T. G. Delbridge, manager, research and development department, The Atlantic Refining Company, Philadelphia, Pa.; members of executive committee, O. U. Cook, assistant manager, department of metallurgy, inspection and research, Tennessee Coal, Iron, and Railroad Company, Birmingham, Ala., H. F. Gonnerman, manager, research laboratory, Portland Cement Association, Chicago, Ill., C. S. Reeve, manager, research development, The Barrett Company, Leonia, N. J., F. E. Richart, research professor of engineering materials, University of Illinois, Urbana, Ill., and F. M. Waring, engineer of tests, The Pennsylvania Railroad Company, Altoona, Pa.

National Power Show. The management of the National Exposition of Power and Mechanical Engineering has announced that the 1936 exposition will be held in New York, N. Y., from November 30 to December 5, inclusive, coincidental with the annual meeting of The American Society of Mechanical Engineers.

American Engineering Council

Engineers' Relations to Creating Employment

All of the Washington palliatives have failed so far to make any real dent in the number of unemployed, according to the May "News Letter" of A.E.C. Estimates of unemployed vary from 8 to 14 million, but the estimators, whether they are on the high side or the low side, have not changed their estimates materially in 3 years. Statistics on unemployment, of course, are notoriously inadequate, but the broad fact remains that the total number of unemployed today is approximately the same as it was 3 years ago. Outside of this simple fact, however, the employment situation is full of paradoxes. It is known that there is a definite shortage of skilled help in the building trades in some localities and if there should be any large advance in the machinery industries, there would be a dearth of skilled mechanics, toolmakers, and other trained craftsmen.

As reported before in this "News Letter," the government policy, expressed in a nutshell, continues to be a "work-relief" policy under WPA. Many engineers are employed in the government, in PWA and WPA and in some 70 other departments or divisions, but indications are that during the months to come an increasing number of men will be dropped from the government payrolls and among these will be several thousand engineers. It should be fair to prophesy, therefore, that the employment of engineers by the government has reached its peak and that there will be a gradual recession in the number of those so employed. Meanwhile, private employment of engineers slowly is increasing. One of the indexes of this increase is seen in the return of engineers to membership in local and national engineering organizations.

Engineers, however, have more than a personal relation to questions involved in national re-employment policies. With the return of more normal conditions, the engineer is an employment creator. Re-employment of men in large numbers depends, fundamentally, on the re-employment of capital for the production of new materials, new machines, new buildings, etc. The engineer led and managed capital goods and construction industries still lag behind the so-called consumption goods industries. The fundamental reasons for this lie outside the field of technology and in the realm of finance and economics. The public eventually must become conscious of the fact that the re-employment of capital underlies the re-employment of men, and until our national policies with regard to taxation, federal controls of industry practices, and the determination of broad labor policies are settled, the normal processes of re-employment of capital will not take place. Meanwhile, there is an awakened interest in this whole problem outside of government. At the meeting of the U.S. Chamber of Commerce, several phases of the problem of re-employment were presented and a very real stimulus given to the thought that new products, new services, and new inventions, all engineer-created products, presented one of the most hopeful opportunities for the re-employment of capital and consequently the re-employment of men.

Under the WPA, $12,000,000 was allotted last December for a study under a national research program of "re-employment opportunities and the changes in the techniques of production." This study is just getting under way under the direction of David Weintraub with headquarters at Philadelphia, Pa. Some of the factors that are proposed include the measurement of the volume of technological unemployment, changes in productivity in selected groups of industries, and the historical analysis of the development of techniques in relation to the development and standards of living.

There is need of engineering statesmanship in a consideration of this total problem. There is at present no basic statistical data upon which decisions can be made as to the influence of technology on employment. The government already is starting to tax payrolls for social security without knowing yet how many people are employees and how many are employers. It seems evident that if tax payrolls be taxed to provide money for pensions, unemployment insurance, etc., payrolls will be reduced. When this happens, probably someone will decide to tax machine output and we will enter a vicious circle of increased production costs, increased cost to the consumer, and a further reduction in the number of employed. The A.E.C. committee on the relation of consumption, production, and distribution has expressed the belief that an "economy of abundance must replace an economy of scarcity," to use the latest phrase, if we are to find the answer to a rising standard of living in the United States. Several areas of this whole question can profitably be studied from an engineering viewpoint and it is anticipated that the committee on engineering economics of Council will give consideration to some of these questions.

Standards

New Rotating Electrical Machinery Standards

The recent publication in a single volume of American standards for rotating electrical machines marks an important step in the progress of standardization of electrical apparatus initiated by the A.I.E.E. in 1899. The present standard combined those standards of the National Electrical Manufacturers Association that are of general interest, and the entire scope of the former A.I.E.E. standards for d-c, synchronous, and induction machines, synchronous converters, and a-c and d-c fractional horsepower motors (former A.I.E.E. Standards numbers 5, 7, 8, 9, and 10 are now superseded by the new publication).

The N.E.M.A. rules have related particularly to manufacturing practice with respect to types of machines, values for rating purposes, dimensions, and structural details. The chief purpose of A.I.E.E. standards on the other hand has been to define the terms and conditions that characterize rating and behavior with special reference to the conditions of acceptance tests. Under American Standards Association procedure the 2 sets of rules have been harmonized and an American standard, complete in all important items, is now available. This pamphlet (C50) of 100 pages is obtainable from A.I.E.E. headquarters at a cost of $1.30 per copy with the usual 50 per cent

discount applying on single copies to A.I.E.E. members.

New Lightning Arrester Standards

For quite a number of years the A.I.E.E. through its committee on protective devices has been at work developing a standard for lightning arresters designed for the protection of a-c power circuits. The first 2 reports of the subcommittee having direct charge of the work, under the chairmanship of I. W. Gross, American Gas and Electric Company, were issued in pamphlet form for purpose of criticism. Following careful consideration of the suggestions received, the final report was approved by the Institute and the American Standards Association, and became an American standard on January 30, 1936. To complete this standard has been difficult because of the rapidity with which the art has changed. It seemed wise, however, not to await further developments, but to establish these standards realizing that they represent but a step in the progress of the art of protection of electrical equipment against the effect of lightning and other overvoltages. This standards pamphlet, A.I.E.E. number 28 (ASA-C62) can be obtained from A.I.E.E. headquarters at a cost of 30 cents per copy with the usual 50 per cent discount applying on single copies to A.I.E.E. members.

Revision of Oil Circuit Breaker Standards

The committee on protective devices has developed a proposed revision of the present A.I.E.E. Standard number 19, Oil Circuit Breakers. This was presented to the standards committee at its meeting of April 29, and in view of the fact that the oil circuit breaker standard is now before the sectional committee on power switchgear, it was decided to arrange for the printing of the protective devices committee's revision as a report on a proposed revision. This report is now in course of publication.

Revised Sphere-Gap Spark-Over Voltages

A revision of sphere-gap spark-over voltage values as published in A.I.E.E. Standard number 4 has been completed. The new data with statement on status is published in this issue of Electrical Engineering, page 783.

Test Code Proposed for Instruments and Measurements

From several sources the standards committee has received suggestions that there be developed a test code for instruments and measurements. Some material of this nature is now included in the other test codes already developed, as well as in an "Electrical Measurements" section of the Power Test Code of the American Society of Mechanical Engineers. However, as there is some difference of opinion on the necessity for a separate and complete code of this type, the standards committee at its meeting of April 29 referred the question to the instruments and measurements committee with a suggestion that they thoroughly investigate the situation before taking any definite action.

Revision of Automatic Station Standards

An A.I.E.E. standard for automatic stations, number 26, was originally approved in 1928 and was revised in 1930. A further revised form was approved in January 1936. This standard was developed under the auspices of the committee on automatic stations of the Institute, M. E. Reagan, chairman. The standards committee directed that it be submitted to the American Standards Association for consideration as a possible American standard. Copies of the revised Standard number 26 will not be available until action by ASA is determined.

Fuse Standards Report Approved

At the April 29, 1936 meeting of the A.I.E.E. standards committee a report on a proposed standard for fuses above 600 volts was presented. This material was developed under the auspices of the committee on protective devices of the Institute. The standards committee directed that the report be made available in pamphlet form for purpose of criticism and suggestion. The work of publication is now under way.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. Electrical Engineering will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Registration of Engineers

To the Editor:

Referring to my address* on "Registration of Engineers," published in the August 1935 issue of Electrical Engineering, permit me to reply to the discussion* that has followed it in these columns, particularly that contributed by Arthur W. Berresford, past-president of A.I.E.E.

Mr. Berresford has evidently given thoughtful study to the subject, but his conclusions are unfortunately impaired by the mistaken premises underlying his discussion.

In the first place, he assumes that the engineering profession may be categorically divided into 2 parts, engineers serving the public and engineers in private or corporate employment, respectively, and that registration is designed to cover only the former classification. Any such division of our profession would be unfortunate. *Registration is intended to cover the entire profession—all engineers*, whether in public or private employ, whether working for fees or salaries, consulting engineers, designing engineers, engineers in public office, in civil service, in public utilities, and in industrial corporations. This is a fundamental principle and cannot be overemphasized. What our profession needs is the establishment of a clear-cut line of demarcation between the engineer and the nonengineer, and that is the goal of registration. Any thought that registration is intended for only a fraction of the profession impairs our solidarity and retards the progress of our profession toward that goal.

It is true that some exemptions are contained in our registration laws, but this fact should not be made the basis for any confused thinking within the profession. It is not the engineer but the nonengineer who is exempted; not the qualified man but the unqualified. Under these exemptions, nonengineers are permitted under certain conditions to do work of an engineering nature, but such exemptions do not make any individual an engineer. To qualify as an engineer, with full professional rights including the right to use the designation "engineer," a man must be registered.

The exemptions that, regrettably, have been written into our registration laws, generally as a matter of temporary expediency, do not represent the ultimate goal. They are being eliminated as rapidly as conditions permit. In the New York State law, an amendment passed last year stops the practice of engineering by corporations unless the chief executive, all employees doing responsible engineering work, and all employees bearing the designation "engi-

* An address presented at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935, and published in the August 1935 issue of Electrical Engineering, pages 876–81. Letters commenting on this address have appeared in the "Letters to the Editor" columns as follows: September 1935, pages 1014–16; October 1935, pages 1129–30; December 1935, page 1421; February 1936, page 217.

neer" are licensed professional engineers. This new requirement brings engineers in corporate employ or "engineers in industry" under the law. Any precedent set by New York State is important, because it covers nearly $^1/_3$ of the engineering profession in the United States.

The second mistaken premise of Mr. Berresford is his acceptance of the 1930 U.S. census figure of 226,000 as the number of engineers in this country. This figure, frequently cited, merely represents the number of individuals who, without regard to any established definition or qualification standards, recorded themselves in 1930 as "engineers" or in related classifications. No such figure of self-styled "engineers" is pertinent. Only a small fraction of that number are really engineers in the professional sense and can qualify for professional registration. I estimate that there are less than 60,000, perhaps only 50,000, professional engineers in the United States. The rest of the 226,000 self-styled "engineers" are technicians, draftsmen, juniors, apprentices, timekeepers, students, laboratory assistants, foremen, enginemen, contractors, mechanics, electricians, repairmen, plumbers, half-trained men, and impostors. Everyone who is connected with construction or industry seems to think he can consider himself an engineer, even though he lacks the professional education and training. Many of these are accepted for membership in certain technical societies and clubs, but they are not engineers and cannot meet the standards of professional registration.

The spread between the estimated number of 50,000 or 60,000 professional engineers in the United States and the recorded number of 35,000 now registered is explained by the fact of 13 states in which registration laws have not yet been enacted; 3 states in which the registration laws are incomplete, covering only a fraction of the profession; and 8 states in which the laws were enacted only last year and in which the procedure of registration is just commencing. A few more years will practically close the gap.

The revisions in registration laws suggested by Mr. Berresford are unacceptable. They are based on his misconception of the purpose of registration, and their adoption would serve to weaken the laws and to accentuate a cleavage in our profession.

The enforcement cases mentioned in my address covered but 2 states for 1 or 2 years and did not purport to be a complete enumeration. Moreover, the number of prosecutions reported is no criterion of the effectiveness of the registration laws. The policy is one of education, persuasion, and voluntary correction before resorting to court action. The last resort is rarely required. In New York State, with a staff of 8 investigators now assigned to the engineers' law, hundreds of reported violations are investigated and corrected annually, without publicity. From the viewpoint of enforcement, our registration laws were initially weak but are being progressively strengthened. Enforcement is as stringent as the profession in any state is ready to make it.

Even at the exaggerated figures estimated by Mr. Berresford, the cost of registration is small per individual. It is vanishingly small in proportion to the benefits secured. For the average engineer, the total cost of registration *in a lifetime* will rarely exceed \$50; this is but one per cent of the average individual investment in professional education and it is less than $^1/_{20}$ of one per cent of the average total professional income thereby protected and enhanced. The lifetime cost of registration, to the individual, is but a fraction (about $^1/_{10}$) of the lifetime cost of membership in a national technical society, and the same ratio will obtain upon application of Mr. Berresford's procedure of multiplying the cost by the number of individuals.

For a few engineers, registration in more than one state may be required; but the relative number of such cases is almost negligible, and the individuals enjoying such interstate practice generally enjoy incomes that make the trifling cost of registration fade into insignificance. The extent of multiple licensing is generally exaggerated. As registration becomes universal and uniform, this slight extra cost will be eliminated.

Any method of registration, certification, or admission must be handled by boards composed of individuals. This holds true for the other leading professions, with boards of examiners similarly appointed. The appointments are made by the board of regents or by the governor of the state upon nominations made by the respective professions. These are not "political" appointments. The highest standards have been maintained and will be maintained. In some states there is no compensation for the time and services of the board members, and in the other states a "compensation" of \$5 or \$10 per day of arduous work for eminent consulting engineers whose time is worth \$150 to \$300 a day is not a temptation for political manipulation. Only men who are sincerely devoted to the profession and its standards will accept such appointment. It is a position of honor and trust, and in that spirit its responsibilities are respected. In generations of examinations of candidates, there has been no retrogression of standards in the legal and medical professions, and there is even less reason to expect a lowering or betrayal of standards by the trusted representatives of the engineering profession.

Mr. Berresford is wrong in his interpretation of certain phrases in the registration laws. The requirement of "experience in engineering work" must not be confused with "professional practice." The former is subprofessional and refers to apprenticeship, as a subordinate or employee, permitted and required prior to registration. The other is of professional status and requires registration. A record of *"lawful* professional practice" (in another state, or prior to enactment of the registration law) may be accepted as partial evidence of qualification.

The standards set up in the model law and in the individual state laws qualifying for the title of "engineer" *have* been evolved by the profession. If any professional group has had no part in this, it is because such group has failed to co-operate with the rest of the profession. The standard written into the model law and into a majority of the state laws is *higher* than the standards for admission to corporate membership in most of the national technical societies, and this higher standard has since been adopted by the Engineers' Council for Professional Development as its recommended "minimum definition of an engineer." The missing factor in membership requirements is evidence of professional education, by graduation or examination. Until engineering societies honestly apply such educational tests as are specified in the formally adopted "minimum definition," they cannot consistently claim that all their members are engineers. Until engineering societies require professional registration as a prerequisite for membership, they cannot legally and publicly claim that all their members are engineers. The medical and bar associations would regard it as unthinkable to admit to membership any individuals who have not been legally admitted to the respective professions.

I admit that there are imperfections in our present registration laws. These are being corrected (but not along the weakening lines suggested by Mr. Berresford) as rapidly as possible. The present defects are in large measure due to the lack of united action by the profession in a state and by the necessity for compromise in the face of fractional ignorance, selfishness, or prejudice. Certain national and local engineering societies have retarded the registration movement by secret or open antagonism, based on misunderstanding. That is why state societies of professional engineers are being formed and a National Society of Professional Engineers has been organized. Registration is now in force in 35 states. It is an established fact, and its further progress will be forward, not backward. Any fractional opposition will be regarded as antiprofessional, and will only strengthen the need for organizing and integrating the profession to protect and advance the registration movement.

Very truly yours,

D. B. Steinman

President, National Society of Professional Engineers.
Past-President, National Council of State Boards of Engineering Examiners

Calculating Power Factor in a 3 Phase Circuit

To the Editor:

Concerning power factor in a 3 phase circuit, as referred to in a letter to the editor in the February 1936 issue of Electrical Engineering by Joseph A. Balombin (pages 217–18), some friendly comments may not be amiss.

The writer has for many years used the formula:

$$\text{Power factor (in per cent)} = 50\sqrt{\frac{(1+a)^3}{1+a^3}}$$

where $a = \dfrac{W_1}{W_2}$, W_1 being less than W_2.

This is the same fundamental relation with a slightly different method of transformation. Experience indicated that it was easily remembered.

Very truly yours,

C. O. von Dannenberg (A'06, M'30)

Tata Iron and Steel Company, Ltd., Jamshedpur, India

Personal Items

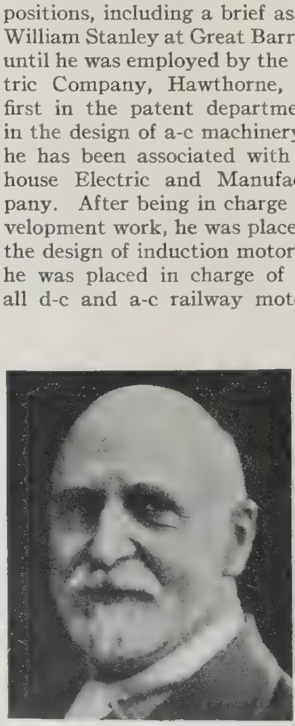
Alex Dow (A'93, F'13, and member for life) president, Detroit (Mich.) Edison Company, has received the 1935 A.I.E.E. national prize award for best paper in public relations for his paper "On the Schooling of Engineers." Mr. Dow was born in Glasgow, Scotland, in 1862, and although he is not a graduate of a technical school, he received the honorary degrees of master of engineering (1911) and doctor of engineering (1924) from the University of Michigan and doctor of science (1935) from the University of Detroit. During the period 1874–82 he was employed as junior clerk and stenographer in a railroad office and in the offices of a steamship company in Liverpool, England. In 1882 he came to the United States, and was employed in various departments of the Baltimore and Ohio Railroad Company. Later he was transferred to the Baltimore and Ohio Telegraph Company to take charge of local line and instrument maintenance, with some construction and experimental work on telephones. In 1888 he was employed by the Brush Electric Company, Cleveland, Ohio, as installation electrician in the Chicago (Ill.) office. In 1889 he became district engineer in that office. In 1893 he accepted the opportunity to design and supervise the construction of the public lighting plant of the city of Detroit, and in 1896 he became vice president and general manager of the Edison Illuminating Company of Detroit. The Detroit Edison Company succeeded the Edison Electric Illuminating Company of Detroit in 1903, and Mr. Dow was retained in a similar position until he was made president in 1913. He designed and supervised the construction of several generating stations of the Detroit Edison system. He served the city of Detroit as the engineer member of the board of water commissioners continually from 1916 to 1930. He is a member of The American Society of Mechanical Engineers, American Society of Civil Engineers, and the Institution of Electrical Engineers (Great Britain).

E. F. Scattergood (A'08, F'13) chief electrical engineer and general manager, Bureau of Power and Light of the City of Los Angeles (Calif.) has received the 1935 A.I.E.E. national prize award for best paper in engineering practice for his paper "Engineering Features of the Boulder Dam-Los Angeles Lines." Mr. Scattergood was born in Burlington County, N. J., in 1871, and received the degrees of bachelor of science and master of science (1893) and the honorary degree of doctor of science (1931) at Rutgers University. In 1899 he received the degree of master of mechanical engineering at Cornell University. During the period 1894–98 he served on the faculty of Rutgers University as instructor in mathematics and electrical science, and after a year's graduate study at Cornell University, he became professor and head of the department of electrical engineering of the Georgia School of Technology in 1899. In 1902 he became associated with the Huntington Light, Power, and Electric Company of Los Angeles, and during the period 1906–09 he maintained his own consulting mechanical and electrical engineering practice in Los Angeles. In 1909 he was appointed chief electrical engineer and general manager of the Bureau of Power and Light of the City of Los Angeles, and has held that position continuously. In that capacity he has been in charge of the design, construction, and management of the Los Angeles municipal hydroelectric generating and distributing system, and in 1933 he was appointed a member of the Federal Public Works Advisory Committee for California. He has been a nonresident lecturer in electrical engineering at Stanford University since 1926. He is a member of the Seismological Society of America, Pacific Geographic Society, Phi Beta Kappa, and Sigma Xi.

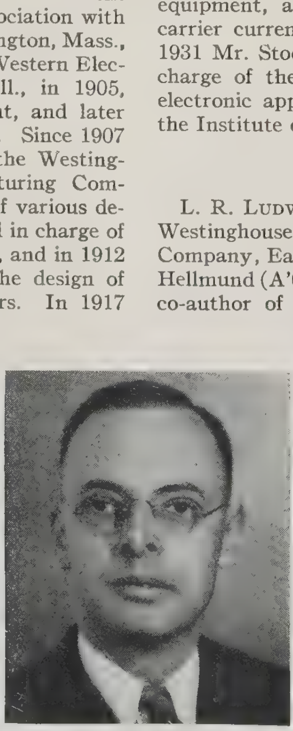
R. E. Hellmund (A'05, F'13, Lamme Medalist '29) chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., with L. R. Ludwig (A'28) co-author of the paper "Sparking Under Brushes of Commutator Machines," has received honorable mention in the 1935 A.I.E.E. national prize awards for best paper in theory and research. Mr. Hellmund was born at Gotha, Germany, in 1879, and attended the Ilmenau Technical College, from which he was graduated with the degree of electrical engineer in 1898. After being engaged in electrical development work for 3 years, he attended the Polytechnikum Charlottenburg, Berlin, as a graduate student. In 1903 he came to the United States and held several different positions, including a brief association with William Stanley at Great Barrington, Mass., until he was employed by the Western Electric Company, Hawthorne, Ill., in 1905, first in the patent department, and later in the design of a-c machinery. Since 1907 he has been associated with the Westinghouse Electric and Manufacturing Company. After being in charge of various development work, he was placed in charge of the design of induction motors, and in 1912 he was placed in charge of the design of all d-c and a-c railway motors. In 1917 Mr. Hellmund was assigned to miscellaneous consulting work, in which he continued until 1922, when he was made engineering supervisor of development. In 1926 he was appointed chief electrical engineer, and in 1933, chief engineer. He has presented many papers before the Institute and has contributed liberally to technical literature in the United States and Europe. He has been a member of the Institute's standards committee since 1930, and is an alternate member of the electrical standards committee of the American Standards Association. He is a member of Electrotechnischer Verein (German Institute of Electrical Engineers) and the Society of German-American Technologists, and was president of the latter society during the period 1920–21.

R. N. Stoddard (M'34) electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1935 A.I.E.E. National prize for initial paper for his paper "A New Timer for Resistance Welding." Mr. Stoddard was born (1895) at Meriden, Conn., and attended the Casino Technical Night School. Following a brief preliminary training with the Potomac Electric Power Company, Washington, D. C., he entered the employ of the Westinghouse Electric and Manufacturing Company as a student engineer at East Pittsburgh. In 1916 he was transferred to the sales department of that company, and during the period 1917–19 he served as an engineer in the radio laboratories of the U.S. Army Signal Corps. In 1919 he returned to the Westinghouse Company as a sales engineer, and in 1921 he accepted a similar position with the Radio Sales and Service Company, Pittsburgh. In 1923 he entered the radio engineering department of the Westinghouse Company to assist in the design and development of carrier current communication equipment, and was placed in charge of carrier current equipment in 1929. Since 1931 Mr. Stoddard has been in responsible charge of the design and development of electronic apparatus. He is a member of the Institute of Radio Engineers.

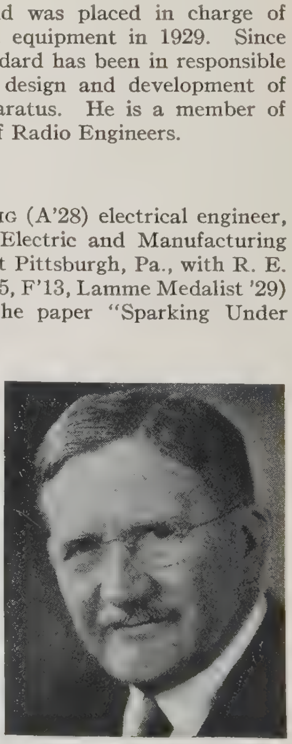
L. R. Ludwig (A'28) electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., with R. E. Hellmund (A'05, F'13, Lamme Medalist '29) co-author of the paper "Sparking Under



ALEX DOW



R. N. STODDARD



E. F. SCATTERGOOD

Brushes of Commutator Machines," has received honorable mention in the 1935 A.I.E.E. national prize awards for best paper in theory and research. Mr. Ludwig was born at Kansas City, Mo., in 1904, and graduated in electrical engineering from the University of Illinois in 1925. Following his graduation he was employed by the Westinghouse Company as a graduate student, and in 1926 he was designated as assistant to the chief electrical engineer, in which capacity he served until he was transferred to the railway motor engineering department in 1928. In 1929 he was awarded a Lamme Memorial scholarship, and during the year 1929–30 he attended the University of Berlin, Germany, as a graduate student. During the period 1931–35 he undertook research work in the Westinghouse laboratories, and more recently he was placed in charge of the air circuit breaker and protective devices division of the switchgear engineerng department. Mr. Ludwig has presented several papers before the Institute, and is co-author of the 1933 A.I.E.E. national prize for best paper in theory and research.

W. S. Conlon (A'20, M'28) formerly engineer-manager of public works, City of Stamford, Conn., recently was appointed executive secretary of the National Society of Professional Engineers, with offices at the national headquarters of that society at Washington, D. C. Mr. Conlon was born at New York, N. Y., in 1895, and attended the Mechanics Institute, New York. Following a preliminary engineering training period of 3 years (1916–18), he served the U.S. Army as electrical instructor and assistant engineer until 1921. He accepted a position as electrical engineer for the Stamford (Conn.) Hall Company in 1921, and during the period 1922–24 he served as valuation engineer for the Pennsylvania Power and Light Company, Allentown, Pa. After a brief return to the Stamford Hall Company, Mr. Conlon became associated with the fixed records division of the Alabama Power Company, Birmingham, in 1925, and during the period 1926–27 he was a member of the electrical engineering staff of the firm of Murrie and Company, New York. In 1928 he became electrical engineer for the consulting firm of Jackson and Moreland, Boston, Mass., and in 1929 he held a similar position with the Coverdale and Colpitts Company, New York. During the period 1930–32 he maintained a consulting engineering office in Stamford, Conn., until he was appointed engineer-manager of public works of that city.

Alfred Herzenberg (A'34) has left the regulator engineering department of the General Electric Company at Pittsfield, Mass., to join the staff of the Shell Petroleum Corporation's geophysical section, with headquarters at Houston, Texas. Mr. Herzenberg, a native (1904) of Berlin, Germany, graduated in electrical engineering from the Darmstadt Institute of Technology, and from Union College, Schenectady, N. Y., with the degree of master of science. He entered the employ of the General Electric Company at Schenectady in 1928, where he remained until 1932, at which time he went to the Massachusetts Institute of Technology (Cambridge) to undertake research in electrical insulation. In 1933 he returned to the General Electric Company, in the works laboratory at Pittsfield, Mass., where he remained until April 1, 1936. Mr. Herzenberg is co-author of a paper "The M. I. T. Power Factor Bridge and Oil Cell," published in Electrical Engineering for March 1935, p. 272–9.

M. W. SMITH

M. W. Smith (A'20) formerly division engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., recently was appointed manager of engineering. Mr. Smith is a native (1893) of Overton, Texas, and graduated in electrical engineering at the Texas Agricultural and Mechanical College in 1915. Immediately following his graduation he was employed by the Westinghouse Company as a student engineer, and his association with that company has been continuous. Mr. Smith has been identified with generator engineering operations, first as a design engineer, later as a section engineer, and more recently as engineer in charge of the design of the large a-c machines of the generator division.

L. S. Goodman (A'11, M'27) former head of the statistical bureau, Edison Electric Illuminating Company of Boston, Mass., has been appointed clerk and assistant treasurer of the company. Mr. Goodman received the degrees of bachelor of philosophy (1905) and master of arts (1908) at Bucknell University, and the degree of bachelor of science in electrical engineering (1908) at the Massachusetts Institute of Technology. During the period 1908–17 he was associated with the consulting firm of D. C. and W. B. Jackson, Boston, and in 1918 he entered the employ of the American International Shipbuilding Corporation, Hog Island, Pa. In 1920 he became assistant superintendent of the statistical bureau of the Edison Electric Illuminating Company, and later was made superintendent of that bureau.

A. E. Watson (A'03, M'15) senior professor of electrical engineering, Brown University, Providence, R. I., will retire from active service at the end of the 1935–36 academic year. Doctor Watson was born at Providence in 1866, and received the degrees of bachelor of arts (1888), master of arts (1898), and doctor of philosophy at Brown University. During the period 1888–95 he served as electrical engineer for the Thomson-Houston Electric Company, Lynn, Mass., and the General Electric Company Schenectady N. Y., and during the same period served as lecturer in electrical engineering in the extension division of Brown University. In 1895 he joined the faculty of Brown University as an instructor in physics. In 1898 he founded the department of electrical engineering as a branch of the physics department, and was appointed assistant professor of physics, with full charge of the adminstration of the department of electrical engineering. In 1914 Brown University recognized the department of electrical engineering as a separate department, and Doctor Watson was appointed assistant professor of electrical engineering. Later he was appointed associate professor of electrical engineering and professor of electrical engineering.

P. J. Ost (M'23) formerly chief electrical engineer, Public Utilities Commission, San Francisco, Calif., has been appointed general manager and chief engineer of the recently formed electric power bureau of the commission. Mr. Ost is a native (1882) of Topeka, Kan., and attended the University of Kansas. After a preliminary training of 3 years in railway construction work, he became signal supervisor and assistant signal engineer for the Atchison, Topeka, and Santa Fe Railway Company in 1904. He became signal engineer for the Pacific Electric Railway Company, Los Angeles, Calif., in 1907, and in 1909 he was appointed assistant city engineer in charge of electrical work for the city and county of San Francisco. He was appointed electrical engineer in 1924 and chief electrical engineer in 1928. In 1932 he accepted a similar position with the public utilities commission of the city of San Francisco, and held that position until he was appointed to the commission's power bureau.

A. G. Steinmayer (A'19) formerly chief engineer, Line Material Company, South Milwaukee, Wis., recently was appointed vice president in charge of engineering. Mr. Steinmayer is a native (1894) of La Salle, and received the degree of bachelor of science in electrical engineering at the University of Illinois in 1916. Following his graduation, he became assistant chief engineer, Electrical Engineers Equipment Company, Chicago, Ill., and remained in that position until he joined the U.S. Army in 1918. In 1919 he returned to the Electrical Engineers Equipment Company, and in 1920 he joined the engineering staff of the Line Material Company with the position of electrical engineer. He was appointed chief engineer in 1934.

E. B. Meyer (A'05, F'27, and president) chief engineer, Public Service Electric and Gas Company, Newark, N. J., recently received the honorary degree of doctor of engineering at the Newark (N. J.) College of Engineering as "a recognized pioneer in

developing improved methods and systems of underground power transmission and distribution; at present, and for many years, prominently identified with the system development of the Public Service Corporation of New Jersey and related companies, in responsible charge of engineering, design and construction; president of the American Institute of Electrical Engineers." Mr. Meyer recently was honored also by Pratt Institute in receiving the diploma of honor of that school.

B. W. Creim (A'20, F'31) formerly chief electrical engineer, Modesto (Calif.) Irrigation District, recently was appointed senior electrical engineer for the Rural Electrification Commission, with offices at Washington, D. C. Mr. Creim is a native (1898) of Chicago, Ill., and attended George Washington University. Following a brief service in the U.S. Bureau of Standards, Washington, he was employed by the Bureau of Power and Light of the City of Los Angeles, Calif., during the period 1919–27. He served as instructor in electrical engineering on the extension division staff of the University of California from 1925 until he was appointed chief electrical engineer of the Modesto Irrigation District in 1927.

A. H. Howell (A'35) graduate student, Massachusetts Institute of Technology, Cambridge, has been awarded one of the 1936 fellowships of the Charles A. Coffin Foundation. Mr. Howell received the degrees of bachelor of science in electrical engineering (1929) at the University of Kansas and master of science in electrical engineering (1934) at the Michigan College of Mining and Technology, and will study the insulation problems associated with the use of compressed gas as the essential cooling medium in high voltage cables for d-c power transmission. The fellowships are awarded annually to encourage and assist in the pursuit of research activities in the field of electricity, physics, and physical chemistry.

W. L. Cisler (M'35) formerly general superintendent of generation, Public Service Electric and Gas Company, Newark, N. J., recently was appointed assistant general manager. Mr. Cisler was born at Marietta Ohio, in 1897, and received the degree of mechanical engineer at Cornell University in 1922. Following his graduation he was engaged as cadet engineer by the Public Service Electric and Gas Company, and has held successively the positions of test engineer (1924–26), assistant chief generating station engineer (1926–27), chief generating station engineer (1927–31), planning and installation engineer (1931–35), and general superintendent of generation (1935–36).

E. B. Paxton (A'22, M'25) General Electric Company, Schenectady, N. Y., has been appointed a member of the A.I.E.E. delegation on the American Standards Association sectional committee on transformers. He is a member of the Institute's committees of electrical machinery and electrical standards, alternate member of the standards councils and electrical standards committee of the American Standards Association, and alternate member of the U.S. National Committee on the International Electrotechnical Commission.

R. J. Kuhn (M'31) former electrolysis engineer, New Orleans (La.) Public Service, Inc., has established a consulting engineering office at New Orleans. Mr. Kuhn is a native (1900) of New Orleans, and received the degrees of bachelor of engineering in electrical engineering (1923) and electrical engineer (1933) from Tulane University. He was employed by New Orleans Public Service, Inc., following his graduation in 1923, and has served that company continuously. Mr. Kuhn's work has consisted almost entirely of electrolysis investigation since 1924, and he will specialize in the investigation of electrolysis and corrosion of pipe lines and other structures.

C. T. Sinclair (A'19, M'29) electrical transmission and distribution engineer, Byllesby Engineering and Management Corporation, Pittsburgh, Pa., has been appointed A.I.E.E. representative on the committee on grounding formed under the auspices of the American Water Works Association in co-operation with the Edison Electric Institute. Mr. Sinclair is a member of the Institute's technical program and power transmission and distribution committees.

L. R. Fink (Enrolled Student) graduate student, University of California, Berkeley, has been awarded a 1936 Charles A. Coffin Foundation scholarship. Mr. Fink received the degrees of bachelor of science in electrical engineering (1933) and master of science (1934) at the University of California. He will study the influence of saturation on transient angular oscillations of synchronous machines. He received a similar fellowship for 1935.

R. W. Porter (Enrolled Student) graduate student, Yale University, New Haven, Mass., has been awarded one of the 1936 fellowships of the Charles A Coffin Foundation. Mr. Porter received the degree of bachelor of science in engineering at the University of Kansas in 1934, and received a 1935 Coffin Foundation scholarship. He will devote himself to a study of transients in the monocyclic network.

F. A. Roberts (A'34) formerly production engineer of the welding division, J. D. Adams Manufacturing Company, Indianapolis, Ind., recently was promoted to superintendent of the welding division. Mr. Roberts, an electrical engineering graduate of Purdue University (1933), has been associated with the company since his graduation. He is a member of Tau Beta Pi and Eta Kappa Nu.

W. A. Andree (A'35) engineer, Southern California Edison Company, Los Angeles, recently won the 1936 first prize of the Pacific Coast Electrical Association for his paper written as a solution to the problem "How Shall We Find a Steady Load for Existing Facilities?" Mr. Andree has been associated with the Southern California Edison Company since his graduation from Stanford University in 1934.

H. M. Van Gelder (A'05, M'13) former chief electrification engineer, Federal Power Commission, Washington, D. C., now is acting as consulting engineer to the trustee of the New York, Westchester, and Boston Railway Company, with offices at New York, N. Y.

J. H. Reynolds (A'34) formerly purchasing agent, Westinghouse Electric Supply Company, Miami, Fla., recently accepted a position as electrical engineer for the Duncan Electric Company, Lafayette, Ind.

E. J. Kelley (A'28) recently accepted a position as sales engineer with the Allis-Chalmers Manufacturing Company, Kansas City, Mo.

Obituary

Meldon Humphrey Merrill (M'35) western manager, Robert W. Hunt Company, San Francisco, Calif., died April 18, 1936. Mr. Merrill was born at Yarmouth, Me., May 14, 1873. He attended Westbrook Seminary, and received the degree of bachelor of science at Tufts College in 1896. Following his graduation, he was employed as central station electrician for the West End Street Railway Company, Boston, Mass., and, following a brief association with the Fairbanks Electric Bell Buoy Company, Boston, he became assistant power representative of the Edison Electric Illuminating Company of Boston in 1897. In 1901 he accepted a position as sales engineer for the Westinghouse Electric and Manufacturing Company, Boston, and held that position until he became sales engineer for the Allis-Chalmers Company, Milwaukee, Wis., in 1911. In 1915 he was appointed vice president of the Concord, Maynard, and Hudson Street Railway Company, Boston, and in 1918 he became vice president in charge of engineering of the Texas Gas and Electric Company, Tennessee Eastern Electric Company, Johnson City Traction Company, Massachusetts Northern Railways Company, and Carolina Gas and Electric Company. In concurrence with his association as vice president in charge of engineering of those companies, he organized the consulting engineering firm of Merrill, Sweeney, and Company, with headquarters at Boston, to manage and operate those companies. In 1920 Mr. Merrill acquired full interest in the firm of Merrill, Sweeney, and Company, and the firm name was changed to M. H. Merrill and Company. In 1923 the properties of the companies, of which he was vice president, were sold, and he continued his consulting engineering practice in Boston until 1924, when he transferred his headquarters to San Francisco, Calif. In 1935 he became western manager for another consulting firm, the Robert W. Hunt Company.

Halbert Paul Hill (A'17, M'18, F'22) president, Halbert P. Hill and Associates, Inc., New York, N. Y., died May 18, 1936. Mr. Hill was born at Memphis, Tenn., October 31, 1872, and attended St. Minards College. During the period 1889–93 he designed and constructed several small generating stations in Indiana and Kentucky, and in 1894 he became engineer for the Diamond Electric Company, Peoria, Ill. At the same time he held the position of electrical engineer with the Warren Electrical Manufacturing Company, Chicago, Ill. During the period 1896–1900 he was associated with the Hill and Miller Company, Washington, D. C., and during the following 3 years (1900–03) he was sales and development engineer for the General Incandescent Arc Light Company. Following a brief period as general manager of the Storey Electric Motor Company, Harrison, N. J., he became district manager (1904) of the Bulloch Electric Manufacturing Company, with offices at St. Louis, Mo. Later, the Bulloch Electric Manufacturing Company was purchased by the Allis-Chalmers Company, and Mr. Hill was transferred to Milwaukee, Wis., as engineer in the contract department of the Allis-Chalmers Company. He served the De La Vergne Machine Company, New York, N. Y., as combustion engineer, from 1906 until he became a partner of the consulting engineering firm of Harvey and Hill, New York, in 1908. In 1910 he acquired full interest in the firm of Harvey and Hill, and the firm name was changed to Halbert P. Hill, Inc. In 1917 he became a partner of the firm of Ophuls, Hill, and McCreery New York, and in 1930 he established an independent consulting engineering firm under the name of Halbert P. Hill and Associates, Inc. Mr. Hill had been a member of the Institute's committee on standards since 1932.

Thomas Spencer (A'03 and member for life) consulting engineer, Prest-O-Lite Company, Inc., Indianapolis, Ind., died April 16, 1936. Mr. Spencer was born at Old Saybrook, Conn., January 16, 1856, and attended Yale University as a special student in mathematics and physics. In 1883 he became associated with the late Thomas A. Edison (A'84, M'84, HM'28) as an electrician in the Thomas A. Edison Construction Company. He assisted in the design of 2 of the Edison generating plants, and in 1886 he was transferred to the Man Construction Company to supervise the electrical construction work of the plants. In 1888 the Man Construction Company arranged to do electrical construction work for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and Mr. Spencer was sent to London, England, by the Westinghouse Company to supervise the construction of a generating station of the Metropolitan Electric Company. He returned to the United States in 1889 and became electrical engineer for the North American Construction Company, Pittsburgh, Pa. That company was dissolved in 1891, and he assisted in the establishment of the Helios Electric Company at Pittsburgh; later the Helios Electric Company was merged with the Standard Electric Company, Peabody, Mass., and Mr. Spencer became superintendent and designer of the resulting Helios Upton Company, with offices at Pittsburgh. In 1918 he became engineer for the National Carbon Company, Cleveland, Ohio, and in 1921 he became consulting engineer for the Prest-O-Lite Company. His service in that capacity was uninterrupted.

Daniel McFarlan Moore (A'93, M'94, F'12, and member for life) retired research engineer, General Electric Company, Harrison, N. J., was shot and killed by an assassin June 15, 1936. Mr. Moore was born February 27, 1869, at Northumberland, Pa., and received his formal education in electrical engineering at Lehigh University during the period 1887–89. In 1890 he associated himself with the late Thomas A. Edison (A'84, M'84, HM'28) in the development of the incandescent lamp; however, he was convinced that light could be produced more efficiently by some means other than the carbon filament lamp, and in 1895 he established his own company under the name of the Moore Light Company. Later, the company was reorganized under the name Moore Electric Company, and he served as vice president and general manager of those companies for 18 years. In 1912 he sold the interests of the Moore Electric Company to the General Electric Company, and became a consulting engineer for that company. Mr. Moore was granted more than 100 patents on gaseous conduction principles and applications. He presented many papers before the Institute, and contributed liberally to technical literature in the United States and Europe. He was a member of the Illuminating Engineering Society.

Paul Engleheart (A'14) superintendent of generation, Guanajuato (Mexico) Power and Electric Company, died February 9, 1936. Mr. Engleheart was born April 25, 1879, at Leicester, England, and graduated from Cambridge University (England) in 1900. During the period 1900–05 he served as an apprentice in the experimental department of A. F. Yarrow and Company, shipbuilders, and after a brief association with Farringdon Works, Ltd., London, England, he went to Mexico (1907) to become refrigeration engineer for the Mexican National Packing Company. In 1910 he established himself in the electrical contracting business at San Luis Potosi, Mexico, and in the following year he became assistant district superintendent of the Guanajuato Power and Electric Company. He left the employ of that company briefly to become superintendent of lines and installations of the Central Mexico Light and Power Company, Irapuato, during the period 1912–13. He returned to the Guanajuato Power and Electric Company in 1914, however, to become superintendent of generation, and his service in that capacity was continuous.

Charles Edwin Hebbert (A'14, M'30) Public Service Electric and Gas Company, Ridgewood, N. J., died January 12, 1936, according to work just received at Institute headquarters. Mr Hebbert was born August 2, 1875, at Guelph, Ontario, Canada, and graduated from Lake Forest Academy in 1899. During the period 1902–05 he was employed by the General Electric Company, Schenectady, N. Y., as test engineer, and in 1905 he became electrical superintendent of the Binghamton (N. Y.) Light, Heat, and Power Company. In 1906 he accepted a position as engineering assistant with Ford, Bacon, and Davis, Inc., New York, N. Y., and after a brief connection as manager of the Electrical Repairing Company, Little Rock, Ark., he became sales engineer for the Interstate Electrical Supply Company, Sioux City, Iowa. During the period 1910–12 he was electrical superintendent of the Pierre (S. D.) Electric Company, and in 1913 he became engineering assistant for the Public Service Electric and Gas Company Newark, N. J. He held that position until he became assistant engineer for the Public Service Production Company, Newark, in 1922. He became assistant engineer for United Engineers and Constructors, Inc., Newark, in 1930, and in 1935 he returned to the Public Service Electric and Gas Company.

Burton Lewis Delack (A'11) general assistant to the vice president in charge of manufacturing, General Electric Company, Schenectady, N. Y., died May 7, 1936. Mr. Delack was born at Morristown, N. Y., January 7, 1882, and received the degree of bachelor of science in electrical engineering at the Clarkson Memorial School of Technology in 1903. Following his graduation he entered the employ of the General Electric Company as a test engineer. In 1905 he was transferred to the railway motor engineering department, and in 1912 he assumed responsibility for the mechanical design of railway motors. In 1919 he was transferred to the Erie, Pa., works of that company as manufacturing engineer and representative of the designing engineer, and in 1923 he was made assistant manager of the Erie works, from which position he was promoted (1926) to assistant manager of the Schenectady works. In 1927 he was appointed acting manager of the Schenectady works, and in 1928 he became manager. In 1934 he was transferred to the staff of the vice president in charge of manufacturing.

James Robert Charlton Armstrong (A'02, F'13) consulting engineer, New York, N. Y., died April 15, 1936. Mr. Armstrong was born in Fermanagh County, Ireland, August 11, 1876, and received the degree of bacheor of arts at the Johns Hopkins University in 1899. Following his graduation he was employed as a test engineer by the General Electric Company, Schenectady, N. Y., and in 1901 he was placed in charge of engineering and construction of several of the General Electric Company's electric transit contracts. In 1904 he became transmission engineer for the New York Central Railway Company, New York, and in 1906 he accepted a position as electrical engineer for the New York City Railway System and the Metropolitan Street Railway System. He held that position until he was appointed chief electrical engi-

neer for the General Vehicle Company, Inc., Long Island City, N. Y., in 1913. In 1916 he established consulting engineering offices in New York, and was retained by several railway, lighting, and industrial companies in that city.

Allan Cunningham (A'23, M'29) president and manager, Allen Cunningham Company, Inc., Seattle, Wash., died April 23, 1936. Mr. Cunningham was born at Glasgow, Scotland, January 15, 1882. He attended the Glasgow and West of Scotland Technical College, and received the degree of bachelor of science at the University of Washington in 1909. After serving an apprenticeship in an engine works in Glasgow, he came to the United States in 1903, and served as draftsman and mechanical engineer for several companies in the United States and Alaska until 1913. He established the Pacific Machine Shop and Manufacturing Company, Inc., at Seattle in 1913, and later reincorporated the company under the name of Allan Cunningham Company, Inc. Mr. Cunningham devoted a great deal of study to the application of electric power to marine auxiliary machinery, and he conducted some of the pioneer work in that field in the United States. He was a member of the American Society of Marine Engineers.

Theodore Beran (A'02 and member for life) New York, N. Y., who retired as New York district manager and commercial vice president of the General Electric Company in 1928, died April 3, 1936. He was born at Springfield, Mass., September 16, 1862, and received the degree of bachelor of arts from the College of the City of New York in 1881. From 1889 to 1891 he was in the railway department of the Sprague Electric Railway and Motor Company, New York, and upon the consolidation of this company with the Edison General Electric Company Mr. Beran became assistant to the district manager. Mr. Beran continued in this position following another consolidation with the General Electric Company, and from 1901 to 1903 was assigned to the British Thompson-Houston Company to organize its commercial department. In 1904 he was made district manager at New York, and in 1926 was elected a commercial vice president. Mr. Beran was a former vice president of the Electrical Board of Trade of New York.

George Robert Murphy (A'02, F'20) manager, Pacific district of the Electric Storage Battery Company, San Francisco, Calif., died May 14, 1936. Mr. Murphy was born July 12, 1875, at Jersey City, N. J., and received the degrees of bachelor of arts (1895) and master of arts (1897) at Fordham University and electrical engineer (1899) at Columbia University. In 1900 he was employed as operating engineer in the New York, N. Y., office of the Electric Storage Battery Company. In 1903 he was transferred to the San Francisco, Calif., offices of that company, being connected first with the operating department, and later with the sales department. In 1916 he was placed in charge of the San Francisco office, and in the same year was made manager of the Pacific district. He was a member of the Society of American Military Engineers.

Henry Adams Morss (A'11, M'11) president and treasurer, Simplex Wire and Cable Company, Cambridge, Mass., died May 6, 1936. Mr. Morss was born August 30, 1871, at Boston, Mass., and received the degree of bachelor of science in electrical engineering at the Massachusetts Institute of Technology in 1893. He entered the employ of the Simplex Electrical Company, Boston, immediately after his graduation, and became a director of that company in 1895, when it was incorporated. In 1903 he became vice president, and in 1916 he became vice president of the Simplex Wire and Cable Company. In 1918 he became treasurer, and in 1920 he was appointed president and treasurer.

Kingsley G. Dunn (A'94 and member for life) retired consulting engineer, Berkeley, Calif., died March 12, 1936. Mr. Dunn served as electrician for the Palace Hotel, San Francisco, Calif., in 1894. In 1899 he became electrical engineer for the British Columbia Electric Railway Company, Ltd., Victoria, and during the period 1903–07 he was associated with C. C. Moore and Company, Seattle, Wash. In 1907 he was employed by Hunt, Mirk, and Company, San Francisco, and in 1909 he became vice president of that company. He held that position until he retired from active service in 1920.

Pienchun Huang (A'32) graduate student, Berlin, Germany, died in January 1936. Mr. Huang was born October 1, 1906, at Hoiping, Kwangtung, China, and received the degrees of bachelor of science in electrical engineering (1929) and bachelor of science in mechanical engineering (1930) at Purdue University and master of science in electrical engineering (1931) at the Massachusetts Institute of Technology. After he completed his graduate studies at the Massachusetts Institute of Technology he went to Berlin, Germany, for further study in electrical engineering.

Irving Frederick Day (A'34) foreman, U.S. Lighthouse Service, Portland, Ore., died January 18, 1936. Mr. Day was born July 24, 1902, at Portland, and received the degree of bachelor of science in electrical engineering at Oregon State College in 1926. Following his graduation, he was employed as electrical designer for the Pacific Power and Light Company, Portland. In 1931 he became assistant head of the mechanical section of the technical division of the U. S. Lighthouse Service, and in 1935 he became foreman of that section.

Julius Meyer (A'92 and member for life) retired consulting engineer, Florida City, Fla., died early in 1935, according to word just received at Institute headquarters. Mr. Meyer was born in December 1855, and his entire technical career was identified with consulting engineering. He maintained a consulting engineering office in New York, N. Y., from 1891 until he retired in 1920.

Membership

Recommended for Transfer

The Board of Examiners, at its meeting on June 10, 1936, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Anderson, S. H., member tech. staff, Bell Tel. Labs., Inc., New York.
Brown, R. D., system operator, Monongahela West Penn Pub. Serv. Co., Fairmont, W. Va.
May, J. P., central station dept., Gen. Elec. Co., Pittsfield, Mass.
Meyer, C. C., technical, Am. Tel. & Tel. Co., New York.
Moak, F. C., service engr., Arma Engg. Co. Inc., Brooklyn, N. Y.
Silverman, J., distribution draftsman, Brooklyn Edison Co., Brooklyn, N. Y.
Staley, M. R., teacher, Mount Pleasant Technical High School, Schenectady, N. Y.
Taylor, H. L., chief inspector of elec. energy and E.E., Dept. of Public Works, Vancouver, B. C., Canada.
Taylor, T. A., member of technical staff, Bell Tel. Labs., Inc., New York.
VanderSchaaf, W. D., asst. engr., Pub. Serv. Elec. & Gas Co., Newark, N. J.
Walker, G. H., asst. E.E., Great Northern Railway Co., Seattle, Wash.
Wieland, H. G., asst. gen. foreman, N. Y. Edison Co., Bronx, N. Y.

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1936, or Sept. 30, 1936, if the applicant resides outside of the United States or Canada.

Abbott, G. E., Club Intl. Inc., Mulberry, Fla.
Ackerman, E. K., Sound Systems Inc., Cleveland, Ohio.
Barnhill, C. V., 1646 Irving St., N. W., Washington, D. C.
Barth, P., Pub. Serv. Gas & Elec. Co. of N. J., Newark.
Bartles, S. F., Eastman Kodak Co., Rochester, N. Y.
Barton, S. N., Mackay Radio & Telegraph Co., Clearwater, Calif.
Bauhan, G. L. T., Rm. 930, Municipal Bldg., New York, N. Y.
Binns, J. E., Mackay Radio & Telegraph Co., New York, N. Y.
Brown, K. E., 1502 Customs House, Boston, Mass.
Bruggeman, J. T., 1297 Lexington Ave., New York, N. Y.
Clark, K. C., Hydro Elec. Pwr. Comm. of Ontario, Toronto, Ont., Can.
Clasen, P., Southwestern Bell Tel. Co., St. Louis, Mo.
Cooke, S. P. W., Brown University, Providence, R. I.
Crone, R. H. (Member), Phoenix Engg. Corp., New York, N. Y.
Croy, H. C. (Member), Commonwealth Edison Co., Chicago, Ill.
Dandelake, J. (Member), Miller Elec. Co., Jacksonville, Fla.
Drummey, J. F., Morganite Brush Co., Long Island City, N. Y.
Edgar, R. B., Pub. Serv. of No. Ill., Evanston.
Everett, M. E., United Fruit Co., San Francisco, Cal.
Flack, C. B., Philadelphia Elec. Co., Pa.
Fletcher, R. H., Mass. Inst. of Tech., Cambridge.
French, A. E., Eastman Kodak Co., Rochester, N. Y.
Geoffrey, E. E., Jr., Electrad Inc., New York, N. Y.
Goss, F. L., 207 So. Broadway, Los Angeles, Calif.
Greene, W. J., 10 Wateredge Ave., Baldwin, N. Y.
Hailes, W. D. (Member), General Railway Signal, Co., Rochester, N. Y.
Hammett, T. F., U.S. Bureau of Reclamation, Denver, Colo.
Henry, I. H. (Member), Bell Tel. Lab., New York, N. Y.
Herrick, D. R., Portland Traction Co., Ore.
Horn, M. C., Kentucky Eagle Coal Co., Carbon Glow.
Howard, O., Oklahoma Gas & Elec. Co., Oklahoma City.
Hummel, H. M., Mifflinburg, Pa.
Hyde, F., Bureau of Pwr. & Lt., Los Angeles, Calif.

Jones, H. L., Oregon State College, Corvallis, Ore.
Jones, Karl P., Grinnell Co. Inc., Providence, R. I.
Keefe, W. E., Gen. Elec. Co., West Lynn, Mass.
Krumze, G. N., Jr., Swift & Co., South San Francisco, Calif.
Kunde, C. O., United Drydocks Inc., Mariners Harbor, N. Y.
Lamb, F. X., Weston Electrical Instrument Corp., Newark, N. J.
Laughlin, James D., Jr., Bureau of Pwr. & Lt., Los Angeles, Calif.
Lerchenmiller, W. G., Bethlehem Industrial High School, Pa.
McLaughlin, A. F. W., Canadian Atlas Steel Ltd., Welland, Ont., Can.
Meyer, A. F., c/o Yuba Mfg. Co., San Francisco, Calif.
Nelson, C. C. (Member), Electric Machy. Mfg. Co., Minneapolis, Minn.
Orth, H. S., Lycoming Edison Elec. Co., Williamsport, Pa.
Richardson, J. F., Cleveland Elec. Illum. Co., Ohio.
Richmond, H. P., Jersey Central Pwr. & Lt. Co., Long Branch, N. J.
Riskac, E. J., Lincoln Electric Co., Cleveland, O.
Rothe, F. S., Metropolitan Edison Co., Reading, Pa.
Russell, H. W., Battelle Memorial Institute, Columbus, Ohio.
Ryan, E. C., Ohio Brass Co., Mansfield, Ohio.
Scanlan, W. J., Eastman Kodak Co., Rochester, N. Y.
Schooley, F. (Member), 604 Broadway, Highland, Ill.
Schroder, J. W., Paraffine Co. of Emeryville, Calif.
Scott, E. O., Electro Metallurgical Co., Welland, Ont., Canada.
Seger, R. G., United Electric Controls Corp., Hoboken, N. J.
Steinbuehler, E. A. (Member), Brooklyn Edison Co. Inc., New York.
Trofimov, L. A. (Member), Elec. Controller & Mfg. Co., Cleveland, O.
Trout, C. L. (Member), Union Gas & Elec. Co., Cincinnati, Ohio.
Waldeisen, E. F., 46 W. 4th St., So. Williamsport, Pa.
Waldron, C. J., U.S. Court House & Custom House, St. Louis, Mo.
Ware, L. A., Montana State College, Bozeman, Mont.
Weller, E. A., Consolidated Gas Elec. Lt. & Pwr. Co., Baltimore, Md.
Welton, W. R., National Tube Co., Ellwood City, Pa.
Wier, A. J., Bell Tel. Labs., New York, N. Y.
Wylie, A. P., General Electric Co., New York, N. Y.
66 Domestic

Foreign

Aldrey, J. L. (Member), Apartado Postal 935 Caracas, Venezuela, So. Am.
Chatterjee, B. C. (Fellow), Hindu University, Benares, India.
de Groot, W. (Member), N. V. Philips' Gloeilampenfabrieken, Eindhoven, Holland.
Jakeman, R. G. (Member), Gen. Elec. Co., Witton, Birmingham, England.
Jobling, H. B., Victoria Falls & Transvaal Pwr. Co., Ltd., Germiston, Transvaal, So. Africa.
Krishna Murthy, D., Surat Electricity Co. Ltd., Surat, India.
Lineker, A. W. (Member), Rand Water Board, Johannesburg, Transvaal, So. Africa.
Nehra, P. S., M/S British Insulated Cables Ltd., Peshawar, Cantt., India.
Rudra, J. J. (Member), Coll. of Engg., Guindy, Madras, India.
9 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Blocksom, Franklin C., Randle, Wash.
Bukley, E. J., Malaja-Dmitrovka D. 8 Kv. 38, Moscow, U.S.S.R.
Burns, Arthur E., 1958 E. 29th St., Brooklyn, N. Y.
Collins, Ogie B., Minimum, Mo.
De Keyser, Jacques F., 37–53—78th St., Jackson Heights, N. Y.
Dixon, James E., 411 E. Green St., Clinto, Mo.
Johnson, James W., 3506—16th St., N. W., Washington, D. C.
Jones, Robert W., 565 Thompson Ave., Donora, Pa.
Luther, Herbert A., 50 Atwood Ave., Johnston, R. I.
Megeath, S. A., Jr., 14 North Ave., Elizabeth, N. J.
Merrill, Warren C., 208 W. 8th St., Los Angeles, Calif.
Millheisler, Charles A., 1417 Catalpa Ave., Chicago, Ill.
Miyota, Nath S., 916½ Howell St., Seattle, Wash.
Murray, Forrest H., 5530 Dorchester Ave., Chicago, Ill.
Ridenhour, W. L., 216 Vance St., Chapel Hill, N. C.
Willson, William H., Jr., 1720—2nd Ave., Cedar Rapids, Iowa.
16 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

AMERICAN YEAR BOOK, a Record of Events and Progress, Year 1935. Ed. by A. B. Hart and W. M. Schuyler. N. Y., American Year Book Corp., 1936. 915 p., tables, 8x5 in., cloth, $7.50. An annual record of the events, personalities and tendencies of each successive year in the United States. Contains sections on history, governmental activities, business, and pure and applied science.

REPORTS on PROGRESS in PHYSICS, v. 2. Ed. by A. Ferguson, publ. by Physical Society, Lond.; printed at University Press, Cambridge, 1936. 371 p., illus., 10x7 in., cloth, 21 s., $5.25. Intended to supply the physicist with reviews of recent developments in his field. Contains reviews on general physics; the quantum theory; atomic physics; geophysical prospecting; radio exploration of upper atmosphere ionization; sound; heat; electrical and magnetic measurements; the charge of the electron; electron tubes; X rays; spectroscopy; optics.

PSYCHOLOGY of HUMAN RELATIONS for EXECUTIVES. By J. L. Rosenstein. N. Y. and Lond., McGraw-Hill Book Co., 1936. 284 p., 8x5 in., cloth, $2.50. Intended to give executives an understanding of the workers whom they lead and supervise. Discusses reasons for human behavior, ways in which individuals face difficulties, personality, kinds of workers, co-operation, and discipline.

QUANTUM THEORY of RADIATION. By W. Heitler. Oxford, England, Clarendon Press; N. Y., Oxford University Press, 1936. 252 p., illus., 10x6 in., cloth, $6.00. Presents a systematized account of the theory from a uniform point of view. Contains an introductory chapter on the classical theory, a development of the quantum theory of radiation in the simplest form of general validity, and discussions of the fundamental applications to atomic physics.

MESSGERÄTE im INDUSTRIEBETRIEB. By G. Wünsch and H. Rühle. Berlin, Julius Springer, 1936. 315 p., illus., 10x6 in., 26.70 rm., cloth. A review of industrial measuring instruments, intended for use as a textbook and a guide for the commercial user.

PRACTICAL DESCRIPTIVE GEOMETRY. By W. G. Smith. 4 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 275 p., illus., 9x6 in., cloth, $2.50. Follows the lines of former texts, but presents the oblique plane and the analytical method in greater detail.

ELEKTROAKUSTISCHE UNTERSUCHUNGEN in HALLRÄUMEN. By H. Frei. Leipzig u. Vienna, Franz Deuticke, 1936. 99 p., illus., 9x6 in., 6.48 Austrian shillings; 4 German marks. Treats the problem of sound fields in closed rooms and describes experiments using various methods of acoustical measurement under different conditions.

THE NEXT HUNDRED YEARS, the Unfinished Business of Science. By C. C. Furnas. Baltimore, Williams & Wilkins, 1936. 434 p., 9x6 in., cloth, $3.00. A description of the present state of scientific knowledge of biology, chemistry, and physics and the social consequences of their development, intended for the general reader.

GRAPHS, How to Make and Use Them. By H. Arkin and R. R. Colton. N. Y. and Lond., Harper & Bros., 1936. 224 p., illus., 10x6 in., cloth, $3.00. An introduction which covers all the usual methods of graphic representation and a variety of uses in business, economics, engineering, and other fields.

ATOMIC PHYSICS. By M. Born, authorized translation of German edition by J. Dougall. N. Y., G. E. Stechert & Co., 1936. 352 p., illus., 9x6 in., cloth, $4.75. A review of modern atomic physics based upon a series of lectures published in German in 1933, and brought up to date.

THÉORIE INVARIANTIVE du CALCUL des VARIATIONS. (Institut Belge de Recherches Radioscientifiques, V. 4). By T. de Donder. Paris, Gauthier-Villars & Co., 1935. 230 p., tables, 10x6 in., paper, 35 frs. Presents recent contributions to the theory of the calculus of variations. The first 2 sections present the invariantive theory; the third section discusses applications to mathematical physics: the electromagnetic field, the field of gravity, undulatory mechanics, and radio.

MACHINERY, EMPLOYMENT and PURCHASING POWER, published by National Industrial Conference Board, N. Y., 1936. 103 p., illus., 9x6 in., cloth, $2.00. Presents available facts regarding the relation of machinery to employment, production, and purchasing power of the American population.

COURS d'EXPLOITATION des MINES. By Haton de la Coupillière. 4 ed. Paris, Dunod, 1936. Illus., 10x6 in., cloth, v. 3, 778 p., 160 frs.; v. 4, 763 p., 155 frs. Devoted to hoisting equipment: (3) discusses cables, winding drums, cages, accessories; (4) describes steam and electric prime movers, safety devices, and cages.

V D I-JAHRBUCH 1936, Die Chronik der Technik. Berlin, VDI-Verlag, 1936. 192 p., illus., 8x6 in., paper, 3.50 rm. A review of the developments in engineering during 1935. All branches of technology are covered, and about 6,000 articles are cited.

RADIO RECEIVING and TELEVISION TUBES. By J. A. Moyer and J. F. Wostrel. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1936. 635 p., illus., 8x6 in., cloth, $4.00. Explains the principles of operation and applications of vacuum tubes in nontechnical language.

NEW ACOUSTICS, a Survey of Modern Development in Acoustical Engineering. By N. W. McLachlan. Lond. and N. Y., Oxford Univ. Press, 1936. 166 p., illus., 7x5 in., cloth, $2.75. A nonmathematical summary of practical developments of submarine devices, loud-speakers, microphones, phonographs, sound films, and aids for the deaf.

Industrial Notes

Simplex Elects Officers.—The Simplex Wire & Cable Co., Cambridge, Mass., announces the election of Everett Morss, Jr., president and treasurer; Charles R. Boggs, vice-president and general manager; Philip R. Morss, vice-president, clerk and secretary, and J. Arthur Gibson, vice-president and assistant treasurer. William S. Davis continues as sales manager with George L. Roberts, assistant sales manager.

New Offices for Ferranti.—The executive and sales offices of Ferranti Electric, Inc., have been moved from 130 W. 42nd St. to larger quarters in the RCA Building, 30 Rockefeller Plaza. The factory also is now occupying new and increased space on W. 53rd St., where modern equipment is being installed.

Cellophane for Wire Insulation.—Putting "turns of copper" in less space by insulating the wire with Cellophane is a new use for this versatile material, according to its manufacturer, E. I. Du Pont De Nemours & Co., Wilmington, Del. This transparent wrapping is less than one thousands of an inch in thickness and comes in fractional inch widths. The wire is wound on the usual wire insulating machines. Special adhesives insure a permanent bond and a dress of lacquer completes the job. Laboratory tests, it is claimed prove its higher efficiency over other materials as an insulation from an electrical and mechanical standpoint, in addition to its space saving quality. Other recent adoptions of Cellophane in the electrical industry are its use in electric cords as a separator between wire and rubber; in industrial cables it has been found of special value.

Trade Literature

Capacitors.—Catalog 127, 24 pp. Describes capacitors for industrial and transmitting applications, in all ranges and capacities. Cornell-Dubilier Corp., 4377 Bronx Boulevard, N. Y.

Railroad Electrification.—Bulletin GEA-2091, 24 pp. Describes the Pennsylvania Railroad electrification from New York to Washington. Illustrates electrical equipment, locomotives, etc. General Electric Co., Schenectady, N. Y.

Indicating Meters.—Catalog 21, 28 pp. Describes a wide range of voltmeters, ammeters, wattmeters, etc., in round, square, portable and edgewise types. The Hickok Electrical Instrument Co., 10514 Dupont Ave., Cleveland, O.

Fuse Switches.—Bulletin 527, 12 pp. Describes porcelain housed cutouts, "Fuswitches" and disconnecting switches... Bulletin 528, 16 pp. Describes open type "Fuswitches" and disconnecting switches. W. N. Matthews Corp., St. Louis, Mo.

Thin Wall Cables.—Bulletin 136, 8 pp. Describes Permex thin wall rubber insulated cables, particularly suited for telephone, supervisory control, etc., or other low voltage circuits requiring many conductors in small compass. Hazard Insulated Wire Works, Wilkes-Barre, Pa.

Transformers.—Bulletin "Power Transformers," 4 pp. Describes power transformers up to 5,000 kva and 60,000 volts. . . Bulletin 4 pp. "Building Uptegraff Transformers." Illustrates steps in the manufacture of various types of transformers. R. E. Uptegraff Mfg. Co., Pittsburgh, Pa.

Motors.—Bulletin 215, 4 pp. Describes type T, 6-pole, heavy duty, d-c motors, 40° C. rating, for general service, constant and adjustable speed duty; open and semi-open styles; sleeve and anti-friction bearings. Reliance Electric & Engg. Co., 1086 Ivanhoe Road, Cleveland, O.

Theatre Lighting Equipment.—Catalog 40, 96 pp. A comprehensive presentation of theatre and auditorium lighting equipment and accessories; floodlighting and special illumination applications. Typical indoor and outdoor installations are illustrated. Kliegel Bros., 321 W. 50th St., New York City.

Rural Electrification Manual.—Catalog, 66 pp. Embraces specifications for overhead rural distribution lines, including single and 3-phase, grounded and non-grounded rural distribution lines up to 15 kv. The drawings and tables included are intended as a guide for general construction practice. Locke Insulator Corp., Baltimore, Md.

Variable Speed Units.—Bulletin 139 "Sterling Speed-Trol Motors," 4 pp. Describes the improved Sterling System Speed-Trol unit, a compact, enclosed, self-contained, infinitely variable speed power unit; ratings $^1/_4$ to 15 hp; this unit supersedes the former Sterling Vari-Speed motor. Sterling Electric Motors, Inc., Los Angeles, Calif.

Heating Systems.—Bulletin, 16 pp. Describes industrial electric heating systems with automatic control. Applications include oil heaters for use in connection with purifying insulating oils for transformers, circuit breakers, etc. Typical installations are illustrated. Hynes Electric Heating Co., 240 Cherry St., Philadelphia, Pa.

Metal-Clad Switchgear.—Bulletin GEA-1661A, 12 pp. Describes type MI-6 metal-clad switchgear, combining oil circuit breakers, disconnecting devices, buses, instruments, meters, current and potential transformers, interlocks, supporting framework, and enclosing covers all in a single unit. General Electric Co., Schenectady, N. Y.

Circuit Breakers.—Bulletin 436, 4 pp. Describes a new high speed circuit breaker particularly applicable as a feeder breaker in steel mills, direct current railway systems or wherever extremely high power concentration exists. Maximum continuous rating of the breaker is 10,000 amperes at either 600 or 1500 volts. I-T-E Circuit Breaker Co., 19th and Hamilton Sts., Philadelphia, Pa.

Galvanometers.—Catalog ED, 40 pp. Describes a complete line of galvanometers and dynamometers, including several newly developed instruments—a narrow-coil galvanometer providing an extremely high voltage-sensitivity combined with a very short period, and a dual galvanometer with all the advantages of a portable lamp and scale galvanometer, with a sensitivity 50 times as great. Specifications and listings have been brought up to date throughout the catalog. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.

Demand Meters.—Catalog GEA-612C, 80 pp. Describes a very complete line of standard demand meters intended for measurement of maximum demand (in kw, kva, and rkva, etc.) and its allied problems; includes indicating, graphic, and printing types for all classes of service. These meters are of the block-interval type and indicate or record the demand, integrated and averaged over a definite time interval. General Electric Co., Schenectady, N. Y.

Transformers.—Catalog 116, 40 pp. Describes a complete line of distribution transformers ranging from $1^1/_2$ to 500 kva, for potentials from 240 to 73,000 volts, and for single or 3-phase circuits. Included is a 24-page "Data Book" which gives complete information in tabular form on all standard voltage ratings and kva sizes, accessories, taps, weights, dimensions, etc. American Transformer Co., 178 Emmet St., Newark, N. J.

Service Restorer.—Bulletin 47, 4 pp. Describes an automatic service restorer, a device for use on 7500–12,500Y volt distribution systems to provide dependable overload protection with either 1, 2, or 3 automatic reclosures at predetermined time intervals. It is designed for single crossarm mounting and is equipped with a spring actuated, manually reset control mechanism that requires no auxiliary power for its operation. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Micromax Recorder.—Catalog N-33A. Describes the new "Silver Anniversary" Micromax now available as an indicating recorder or as an indicating and recording controller not only for temperature but for CO , smoke density, chemical strength, pH, frequency, remote load, etc. The one instrument provides all combinations of indicating, recording, signalling and controlling in a manner unique to this model. Measurements are presented most conveniently; a bold scale and pointer shows the condition at the moment, and a clear record on ten visible inches of strip-chart shows it for the past several hours. On controllers, a second pointer shows control setting. Multi-point records may be in blue or in multi-color. Standard Micromax assemblies have been improved wherever possible; contacts are heavier, and certain other component parts are new. All other Micromax models are also described in the new catalog. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.